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Design and Implementation of Overcurrent Protection Relays Test Bench

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ABSTRACT

Design and Implementation of Overcurrent Protection Relays Test Bench

Khalid Daud Khattak

The electrical power simulator in Engineering Sciences Building (ESB) at WVU was dismantled in July 2018. The simulator was used as a teaching tool for EE students to conduct lab experiments. The power simulator employed electromechanical and microprocessor protection relays, manual isolation and industrial circuit breakers, switches, variable autotransformer (VARIAC), voltmeters and ammeters. During the dismantling, a lot of equipment was retrieved for future possible use. This led to the idea of designing and implementing a simple circuit on a test bench that can be used as a lab equipment to demonstrate the operation of overcurrent protection relays. It was decided to design the circuit so that it employs equipment removed from the power simulator including microprocessor-based SEL-751A Feeder Protection Relays, Westinghouse CO-8 electromechanical relays, variable autotransformer (VARIAC), voltmeter, ammeter, isolation circuit breaker, and a tripping circuit breaker. A circuit test bench, available in the lab, was modified for this purpose. The bench provides the advantage of having a setup on a small and movable platform.

The circuit of the Overcurrent Protection Relays Test Bench has a variable autotransformer with protection relays, protection breakers and changeover switches installed on the primary and secondary side of the transformer. SEL-751A or three electromechanical CO-8 relays, one on each phase, can be selected as the main protection device on both sides of the transformer. There was only one industrial circuit breaker available in the lab. This has been installed on the secondary side. For the primary side, a breaker circuit has been designed and used which uses general-purpose DPDT and electronic relays, DC power supply, voltage limiting resistors, toggle switch and push-

button reset switch. This use of the breaker circuit has saved a lot of costs since most of the components used in the design were already available in the lab.

Based on the cost-effective design, it is planned to design a similar circuit that can demonstrate the operation of differential current protection relay based on SEL-387A Current Differential Relay.

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I also want to extend my deepest gratitude to my parents for their unconditional love and support.

Finally, I am grateful to my uncle Fazal H. Khattak who has always been there for me and made my life considerably easy in a new place.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

This thesis report describes the details of design and implementation of Overcurrent Protection Relays Test Bench. The test bench is designed as a lab apparatus, especially for students and researchers working in the field Protection of Power Systems. The test bench employs microprocessor-based SEL-751A Feeder Protection Relays and electromechanical type Westinghouse CO-8 inverse time overcurrent relays.

1.1 Background and Motivation

The Lane Department of Computer Science Electrical Engineering (LCSEE) at West Virginia University (WVU) had a power simulator installed in the 1970s, Spencer [1]. The original design of the simulator employed analog relays. The simulator was later upgraded with microprocessor-based relays donated by Schweitzer Engineering Laboratories (SEL), Spencer [1].

The department decided to establish an Innovation Lab in the room that housed the power simulator. As a result, the simulator was dismantled in July 2018 and the power system equipment was moved to a new Energy Systems Lab in the Engineering Research Building (ERB) room 219.

Figure 1.1 Front view of power simulator that was dismantled, Spencer [1]

Considering the cost and applications of industrial circuit breakers, VARIAC, switches, resistors, meters, potential transformers, and electromechanical and microprocessor electrical protection relays which were removed from the simulator, it was decided to salvage this equipment for possible future use. The intention to put most of the equipment removed from the simulator into academic use, motivated the idea of designing and building a small test bench that could easily be moved and demonstrate the working of electrical overcurrent protection relays which are one of the key elements in electrical protection systems. The availability of two main types of overcurrent relays i.e., electromechanical type CO-8 inverse time overcurrent relays and the more versatile modern microprocessor feeder protection relays; which apart from providing instantaneous and time overcurrent protection over various US and IEC curves also provide various other protection features, mainly over and under voltage protection, frequency variation protection and power factor lead/lag protection; provided an opportunity to design a test bench that can be used to show the application, working, configuration process and advantages/benefits of both types of relays.

1.2 Scope of Document

Section 2 describes the operation of the Overcurrent Protection Relays Test Bench and can be used as a guide for anyone using the bench. Section 3 provides brief overview of equipment used in the design and implementation of the overcurrent protection relays test bench. Section 4 outlines the step-by-step procedure used for configuring the SEL-751A Feeder Protection Relays to communicate with PC running SEL ACSELERATOR QuickSet® SEL-5030 software through SEL-3351 Computing Platform with Substation SERVER.NET. ACSELERATOR QuickSet® SEL-5030 software can be used to access and modify the relay settings and display relay data, SEL [2] and SEL [3]. Circuit schematics, description of SEL-751A settings, US curves for Inverse Time relays, login passwords and parts list are presented as Appendices.

1.3 Design Challenges

In an effort to keep the cost at minimum, the design attempts at the maximum use of equipment already available in the Energy Systems Lab. The lab has four benches that were used with motor-generator sets for lab experiments. The motor generator set is not used anymore and these benches are used by students for their senior design project for providing electrical connections. Since these benches can be easily moved and four were available, it was decided to modify one of these benches for this project. The dimensions of the panel (approximate dimensions: length = 41.5 in., width = 6 in. and height = 25.5 in.) presented a challenge as the design of three phase circuit required that six electromechanical overcurrent relays, two microprocessor feeder protection relays, three breakers and a variable autotransformer fit into the panel. The layout of the Overcurrent Protection Relay Test Bench was greatly influenced by placement of the transformer as it is quite heavy and its depth is almost three times the depth of the connection bench that was selected for this application. The autotransformer had to be placed low otherwise the bench would have become unstable due to the weight and dimensions of the transformer.

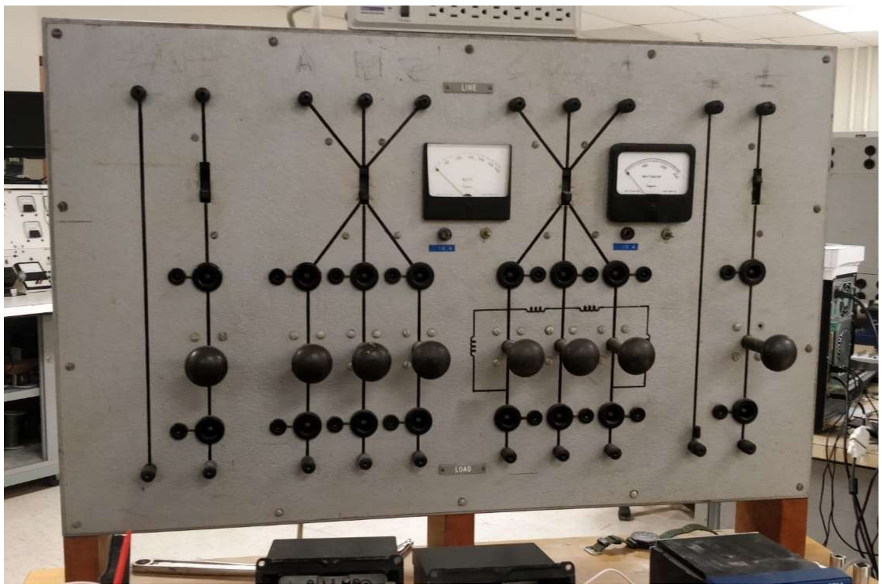


Figure 1.2 Connection bench that was modified for the overcurrent relay setup

Very less information was available about the power simulator that was removed. By design, SEL relays, installed in the power simulator, were connected with SEL-3351 Computing Platform, which can support multiple devices. However, no description of the communication setup between the relays and the Computing Platform and between the Computing Platform and lab PC was available. This presented an issue and required considerable time to address.

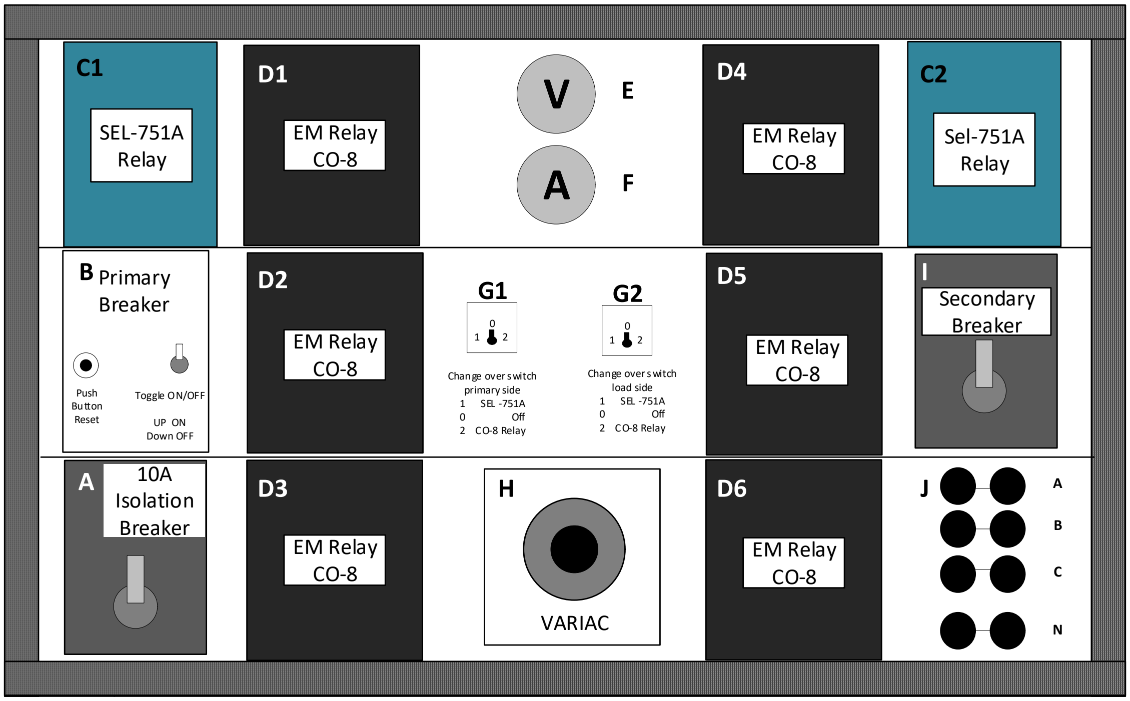
The circuit design of the Overcurrent Protection Relays Test Bench requires the use of two circuit breakers that can be operated by overcurrent protection relays. One circuit breaker is required at the transformers primary side and the other circuit breaker is required at the transformer secondary side. Only one industrial circuit breaker was available in the lab. This has been used at the secondary side of the transformer. Ordering a new circuit breaker for the primary side was not an option as that would have raised the cost considerably. Instead, a breaker circuit for primary side protection had to be designed.

Chapter 2

System Design and Working

Figure 2.1 shows the front view of the Overcurrent Protection Relay Test Bench. Figure 2.2 shows the layout diagram of the front panel of the Overcurrent Protection Relay Test Bench. Figure 2.3 shows the functional diagram of the bench. Detailed wiring schematics of Overcurrent Protection Relay Test bench are given in appendix A.

Figure 2.1 Front view of the Overcurrent Protection Relay Test Bench



A- Westinghouse 10A Manual Isolation Breaker
B- Transformer Primary Side Protection Breaker Circuit
C1, C2 - SEL-751-A Feeder Protection Relay
D1, D2, D3, D4, D5, D6- Westinghouse CO-8 (Inverse Time) Electromechanical Overcurrent Relays
E- GE AC Voltmeter 0-300VAC
F- GE AC Ammeter 0-5A
G1, G2- Manual Changeover Switches
H- Auto Transformer (VARIAC)
I- GE Industrial Circuit Breaker for Transformer Secondary Protection
J- Load Connection Ports

Figure 2.2 Front layout of the Overcurrent Protection Relay Test Bench

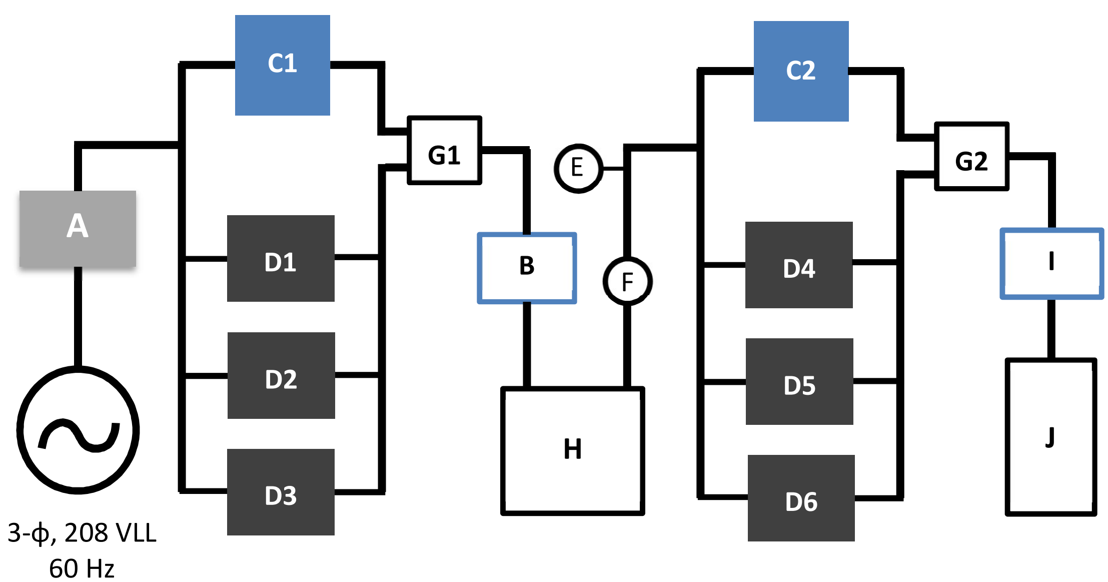


Figure 2.3 Functional diagram of the Overcurrent Protection Relay Test Bench

The wiring schematic implemented in the Overcurrent Protection Relays Test Bench is similar to application example provided in SEL [2] (pp. 2.28 and 2.29). The circuit design implemented in the Overcurrent Protection Relays Test Bench, however, employs two different types of protection devices, i.e. microprocessor SEL-751A and electromagnetic type Westinghouse CO-8 relays. The implemented design uses change over switches (G1 and G2) to select between microprocessor SEL-751A and electromagnetic type Westinghouse CO-8 relays. The implemented design also does not use current transformers (CTs), for current measurement, or potential transformers (PTs), for voltage measurement, and instead current and voltage wiring are done directly with the devices. Moreover, the circuit employed in the test bench does not utilize neutral current measurement through SEL-751A for neutral overcurrent measurement.

The test bench utilizes a 3-phase variable autotransformer-VARIAC (H) with both the primary and secondary windings connected in wye configuration. At the primary side of the transformer; it has one microprocessor-based SEL-751A Feeder Protection Relay (C1), that measures current in the three phases, A, B and C; and three Westinghouse electromechanical overcurrent protection relays (D1, D2 and D3), one for each of the three phases A, B and C. The current path to the primary side can be selected either through SEL-751A (C1) or through the electromechanical relays (D1, D2 and D3), using cam selector switch (G1). Moving the selector switch to '1' position will establish the circuit through SEL-751A. Overcurrent protection to the primary side will depend on the settings of SEL-751A which will send a tripping signal to the breaker circuit at the primary side (B) once a tripping condition is detected by the relay. Selecting '2' on the selector switch (G1) will establish the circuit through the electromechanical relays (D1, D2 and D3). At this selection, overcurrent tripping will depend on the settings of these relays. D1, D2 and D3 have their output contacts in parallel (logical OR). Closing of any one of these relays will send a tripping signal to breaker circuit (B). When G1 is moved to '0', both of the relays are disconnected and no voltage will be applied to the autotransformer (H).

The secondary side of the auto variable transformer (H) also has the same arrangement. In this case, SEL-751A (C2) or electromechanical relays (D4, D5, and D6) can be selected by the cam switch (G2). At the secondary side of the autotransformer (H), an AC voltmeter (E) that measures line to line voltage between phases A and B, and an AC ammeter (F) which measures the current in phase A, are also installed. Based on the selection made on G2, tripping signal is issued to the industrial breaker (I) when output contacts of C2; or the contacts of any one of D4, D5 or D6 are closed. The voltage supply lines are fed through breaker (I) to load connection ports (J).

The bench does not utilize CTs or PTs for current and voltage measurements. The maximum rated current of the autotransformer (H) limits the maximum current of the test bench to a value of 3.5 A. The primary voltage is 3 phase, 208 V_{LL} at 60Hz. The voltage at the secondary side can be adjusted to any value between 0-208 V_{LL} with the autotransformer.

2.1. Procedure for Using the Overcurrent Protection Relays Test Bench

The step by step procedure for using the Overcurrent Protection Relays Test Bench is given as follows,

1) Connect the three-phase load at the load connecting ports (J) in either wye or delta configuration.
2) Select either microprocessor SEL-751A relay (C1) or the electromechanical relays (D1, D2 and D3) from the selector switch (G1). For the selector switch, the setting options are,

   ‘0’- Circuit disconnected from the primary side
   ‘1’- SEL-751A microprocessor relay
   ‘2’- CO-8 electromechanical relays

3) Similarly select the relays on the secondary side using selection switch (G2). The selection option for selector switch on the secondary side (G2) are similar to the selection options on the primary side (G1) given in step 2.
4) Apply power to the test bench by moving the handle of the isolation breaker (A) up.
5) Turn on the breaker protection circuit on the primary side (B) by moving the on/off toggle switch to the upper most position. Push the reset push-button of the breaker circuit.
6) Turn on the industrial breaker (I) by moving its handle in the up position.
7) Increase the voltage by turning the handle of variable autotransformer (H) in clockwise direction. The voltmeter (E) should show the secondary line to line voltage. If the load

switches are on then phase current will be indicated on the ammeter (F). The current should not exceed 3.5 A at any point.

8) Relay selection or change in the relay settings should not be done when the system is energized. Before changing the relays with selector switches (G1 and G2) or changing the relay settings, it is important to turn off the power by moving the handle of isolation switch (A) down to the off position.
9) Depending on how the relays are set, if the industrial breaker (I) trips, then its handle will move to tripping position (between the on and off handle position). The breaker is reset by first moving the handle to off position (down) and then to the on position(up). If SEL-751A is selected from the selector switch then these should be reset by pressing the “Target Reset” button on the keypad panel of the relays. If the breaker circuit on the primary side (B) causes the trip, then it has to be reset by pressing the reset push-button. In case there is no fault, the relay should reset.

2.2. System Limitations

As stated before, the Overcurrent Protection Relays Test Bench does not use CTs or PTs. The maximum current is limited to 3.5 A. Primary side voltage is fixed at 3 phase 208 V_{LL}.

The system has been tested with resistive loads only. In case of reactive loads, it is recommended to use inductive load in parallel with a resistive load.

The communication setup of SEL relays in the test bench utilizes serial communication; and at a time, only one SEL relay can be connected with PC running ACSELERATOR QuickSet® software. The communication setup is discussed in Chapter 4.

Chapter 3

Hardware Details

A brief overview of the equipment used in the test bench is provided as follows.

3.1 10A Isolation Breaker (A)

A 10A, 3-phase manual breaker is used as the main isolation for the Overcurrent Protection Relays Test Bench. This breaker was removed from the power simulator.

Figure 3.1 Main isolation breaker

3.2 Transformer Primary Side Protection Breaker Circuit (B)

The circuit of the Overcurrent Protection Relays Test Bench requires two circuit breakers; one at the primary side and the other at the secondary side of the autotransformer (H). Only one industrial circuit breaker was available which has been used at the secondary side of the transformer. For the primary side, a circuit employing solid state relays, 15 VDC power supply, voltage limiting resistors and a general-purpose double pole double throw (DPDT) relay, has been designed and used. The functional diagram of the breaker circuit is given in Figure 3.2. The detailed wiring schematic of breaker circuit is provided in appendix A-2.

S-1 is a general-purpose 12 VDC, DPDT relay which serves as control of the breaker circuit. S-2, S-3 and S-4 are solid state relays each with one normally open (NO) contact. The NO contacts of these relays are used as switches for the three phase voltages connected to the primary side of variable autotransformer (H). DC voltage from a 15VDC power supply is fed to supply points of S-2, S-3 and S-4 through a toggle switch, which serves as an on/off switch for the breaker, and a normally closed contact of S-1. The coil of S-1 is connected to the power supply through a voltage limiting resistance and a parallel combination of output contacts of SEL-751A Feeder Protection Relay (C1) and three CO-8 electromechanical overcurrent relays (D1, D2 and D3). Voltage supply to S-1 from either SEL-751A (C1) or CO-8 overcurrent relays (D1, D2 and D3) can be selected using the cam changeover switch (G1). A NO contact of S-1 is connected in parallel across the output contacts of relays C1, D1, D2 and D3 and the positive supply going into the coil of S1. This circuit is completed through a push-button reset switch.

Under normal operation S-2, S-3 and S-4 remain energized through the NC contact of S-1 and the output contacts of these relays remain close. When a fault is detected by a selected protection relay, the output contacts of the protection relay will close. This results in voltage being applied to the coil of S-1. NC contact of S-1 will open and this will cutoff the supply to S-2, S-3 and S-4 and contacts of these relays will open thereby disconnecting the AC circuit and cause a trip. As the current level drops, the output contacts of the protection relays will open since these are non-latching. In this scenario, the supply to the coil of S-1 is maintained through its NO contact. The breaker can be reset by the push-button reset switch which momentarily disconnects the supply to S-1. NO contact of S-1 will open and the supply to S-1 will be disconnected. Provided no fault is detected by the microprocessor protection relay C1 or electromechanical relays D1, D2 or D3 (depending on which relay is selected), S-1 will remain disconnected. NC contact of S-1 will close and provide voltage to S-2, S-3 and S-4 and the AC circuit will be closed.

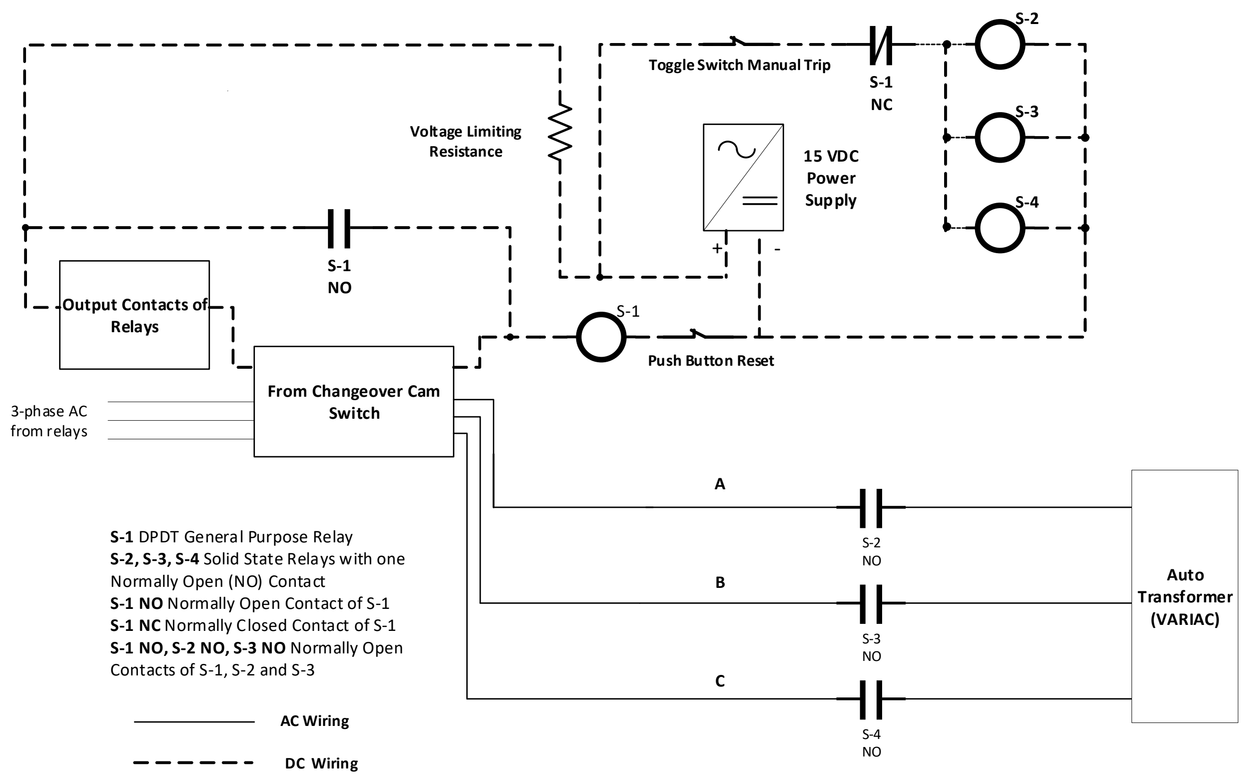


Figure 3.2 Functional diagram of breaker circuit for transformer primary side protection

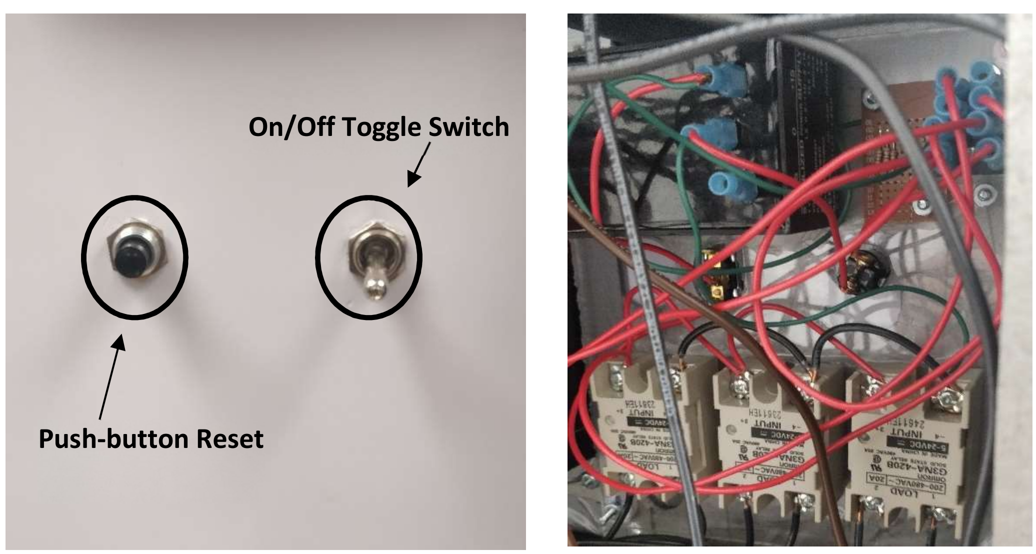


Figure 3.3 Front and rear view of the breaker circuit used for primary side protection

3.3 SEL-751A Feeder Protection Relay (C1 and C2)

This section gives a brief overview of SEL-751A Feeder Protection Relay. Complete information is available in SEL [2]. The Overcurrent Protection Relays Test Bench utilizes two SEL-751-A Feeder Protection Relays. Relay C1 is installed on the primary side of the variable autotransformer. Relay C2 is installed on the secondary side of the variable autotransformer. SEL [2] presents details about the applications, operation and setup of SEL-751A Feeder Protection Relay. The relay is versatile and provides a lot of protection features. As per SEL [2] and the setup menu of relays installed in the bench, the relays can provide protection against instantaneous overcurrent for phase overcurrent (50P), residual overcurrent (50G), neutral overcurrent (50N), negative sequence overcurrent (50Q); time overcurrent protection over various curves (both US and IEC) for phase overcurrent (51P), negative sequence overcurrent (51Q), neutral overcurrent (51N) and residual overcurrent (51G); voltage protections including undervoltage (27), overvoltage (59); power factor protection (55); and frequency protection (81). SEL [2] mentions other protection as well, but here, only those protection features are mentioned that are available in the setup of the relays installed in the test bench.

The relay can support various communication protocols including SEL communication protocols (SEL ASCII, SEL Compressed ASCII, SEL Fast Meter, SEL Fast Operate and SEL Fast SER), DNP3, Modbus and IEC 61850. The device has various ports for EIA-232, EIA-485, Ethernet and Fiber-Optic communication options. For the test bench, EIA-232 serial communication through serial port 3 (COM3) has been used. SEL ASCII commands can be issued using the Terminal in QuickSet software.

SEL-751A has different input and output contacts. The relays installed in the test bench have 3 output contacts (OUT101, OUT102 and OUT103) and 2 input contacts (IN101 and IN102) on the main card in slot A. OUT101 and OUT102 are normally open. OUT103 has both normally open and normally closed contacts. Additional 4 inputs (IN301, IN302, IN303 and IN304) and 4 outputs (OUT301, OUT302, OUT303 and OUT304) are available in slot C. The output contacts can be assigned SEL logic equations. Based on the equation assigned to the output contacts, circuit breakers can be operated. For tripping against protections, a relay word bit TRIP, related with TR equation has to be assigned to an output contact. By default, OUT103 is assigned the TRIP relay word bit.

Figure 3.4 SEL-751A Feeder Protection Relay front view

3.3.1. SEL-751A Wiring Details

The wiring done for current, voltage and output contacts for SEL-751A relays used in the Overcurrent Protection Relays Test Bench are detailed in Table 3.1.

Table 3.1 Details of SEL-751A wiring

Wiring Type	Slot	Slot Terminal Connections
Current	Z	Phase A: incoming = ‘1’; outgoing = ‘2’ Phase B: incoming = ‘3’; outgoing = ‘4’ Phase C: incoming = ‘5’; outgoing = ‘6’
Voltage	E	Phase A: ‘1’ Phase B: ‘2’ Phase C: ‘3’ Ground: ‘4’
Output	A	OUT 103: Connected between ‘7’ and ‘8’

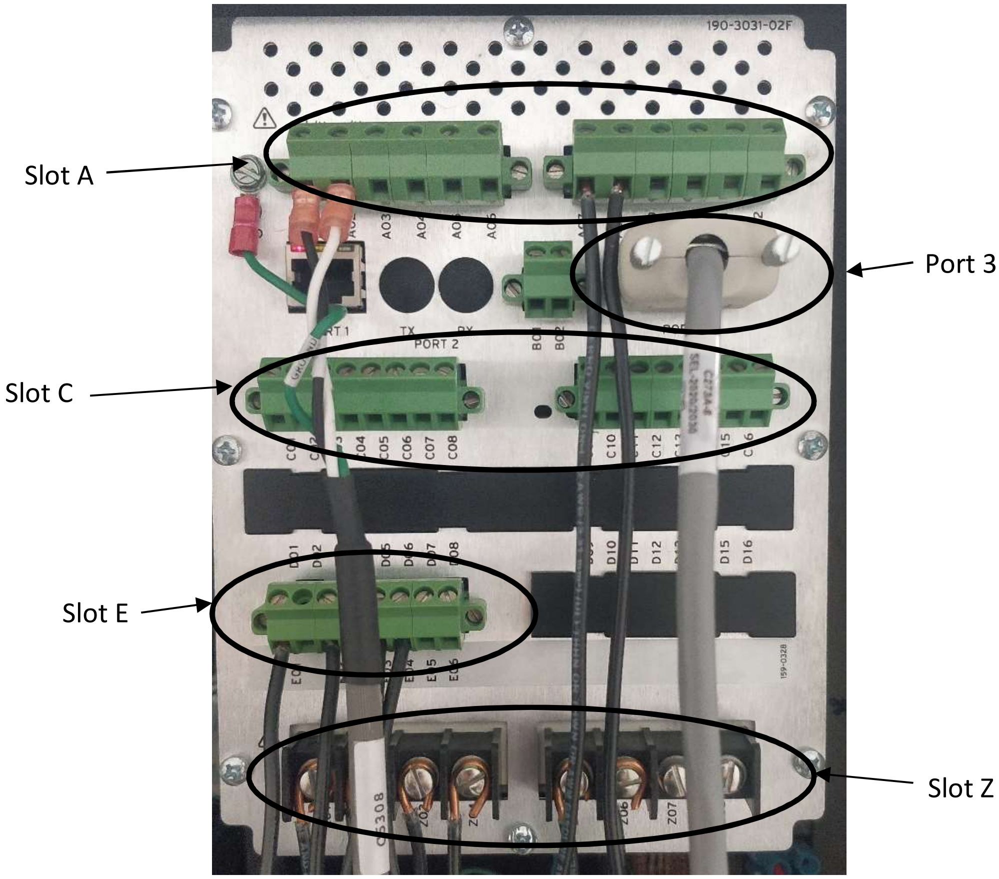


Figure 3.5 Rear view of SEL-751A

3.4 Westinghouse CO-8 (Inverse Time) Electromechanical Overcurrent Relay (D1, D2, D3, D4, D5 and D6)

The Overcurrent Protection Relays Test Bench utilizes six Westinghouse CO-8 inverse time relays. Three relays, one for each phase, are installed on the primary side of the autotransformer. Three relays, one per phase, are installed on the secondary side.

ABB [4] describes the construction, operation, application and installation of the relays. As per the instruction manual ABB [4], the relay employs an electromagnet for overcurrent detection. Out of phase fluxes produced by the electromagnet causes a rotation of a disc. The disc movement is governed by current tap and time dial. Depending on these settings, the disc closes a contact which completes the tripping circuit. Tap setting refer to the minimum current that is required to produce a movement in the disc. The relays utilized in the test bench has tap setting of 0.5, 0.6, 0.8, 1.0, 1.5. 2.0 and 2.5. Tap can be selected by inserting the tap screw at various tap options. This is located above the time dial. Time dial settings can be changed by moving the time dial in clock wise or anti clock wise direction. Settings from 0 to 11 are available. The time dial changes the distance the tripping contact has to travel. Moving from 0 to 11 increases the distance between the contacts. Tap setting screw and time dial are shown in Figure 3.6.

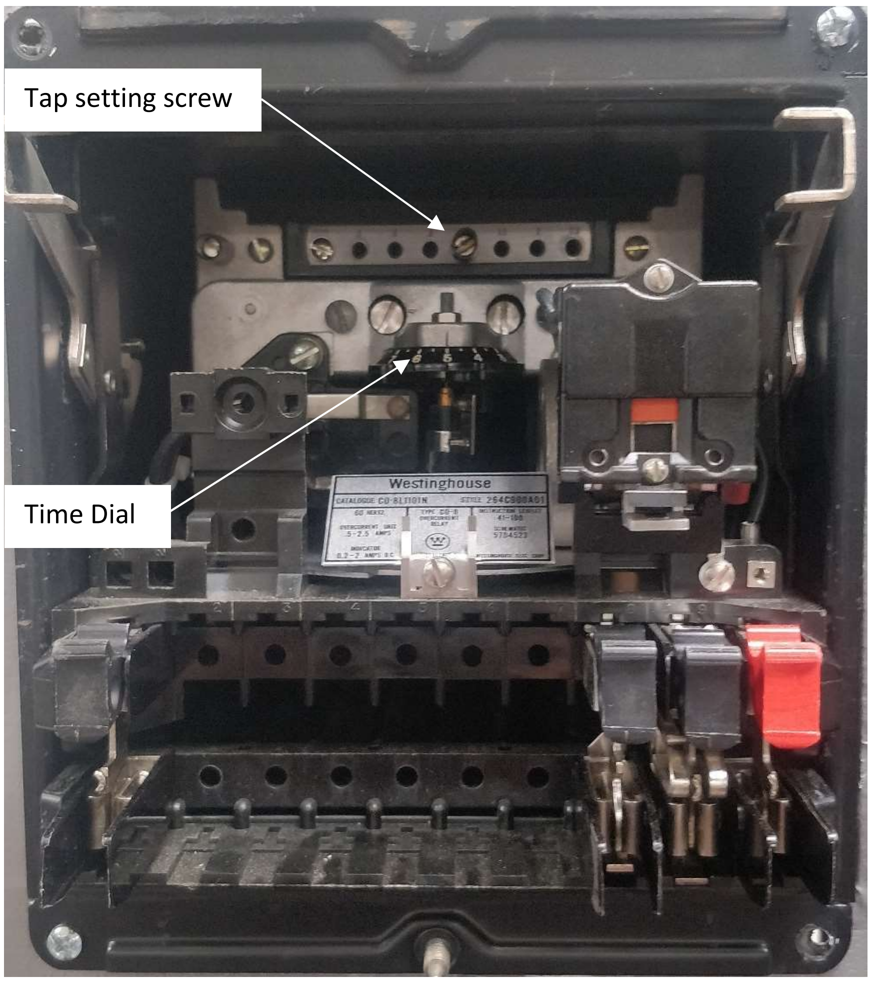


Figure 3.6 CO-8 Electromechanical overcurrent protection relay

The wiring connection used for using the CO-8 electromechanical overcurrent protection relay is detailed in Table 3.2 and shown in Figure 3.7.

Table 3.2 Details of CO-8 overcurrent relay

Wiring Type	Connection Points
AC current	8 and 9
DC tripping contact	1 and 10

Figure 3.7 Rear view of CO-8 electromechanical overcurrent relay

3.5 General Electric (GE) AC Voltmeter (E)

A GE 0-300 AC voltmeter has been installed to measure the line to line secondary voltage applied to load connected at connection ports (J).

Figure 3.8 AC voltmeter installed in the test bench

3.6. General Electric (GE) AC Ammeter (F)

An AC ammeter has been installed to indicate the current flow at phase-A on the secondary side of the variable autotransformer.

Figure 3.9 AC ammeter installed in the test bench

3.7. Primary Side and Secondary Side Changeover Switches (G1 and G2)

Cam Changeover switches have been installed in the primary side (G1) and secondary side (G2) of the variable autotransformer. The changeover switches on either side of the transformer select SEL-751A or electromechanical Westinghouse CO-8 relays installed on these sides. The selector switches have three position. If the selector knob is turned to position ‘1’ then current and circuit breaker tripping paths are established through SEL-751A relays. If the selector knob is turned to position ‘2’ then current and circuit breaker tripping paths are made through electromechanical relays. Selecting ‘0’ will disconnect both types of relays.

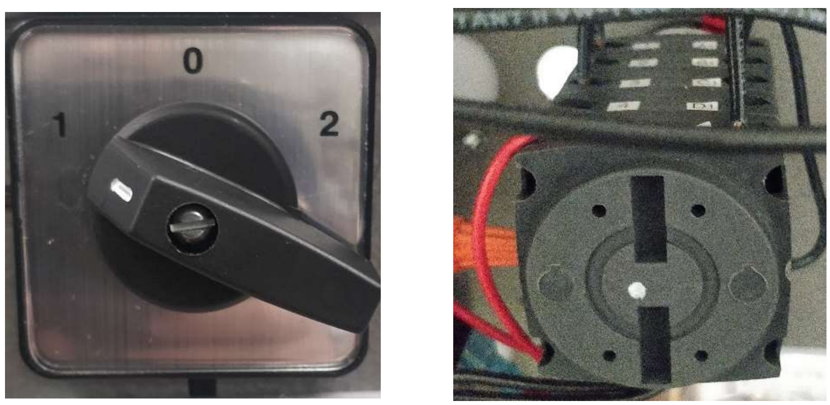


Figure 3.10 Cam changeover switch front and rear view

3.8. Variable Autotransformer - VARIAC (H)

A 3-phase variable autotransformer (General Radio Company VARIAC) is used to provide voltage to the load that can be connected to the secondary side of the transformer through load connecting ports. The primary side is supplied with 3 phase 208 V_{LL}, 60 Hz voltage supply. The secondary voltage can be adjusted from ‘0’ to a maximum of 208 V_{LL} by using the knob shown in Figure 3.8.1. Turning the knob clockwise, increases the voltage and turning it counter clockwise will reduce the secondary voltage. The transformer is rated at 240 VAC, 4 A at 50-60 Hz.

The primary and secondary windings are connected in wye configuration. The primary side is connected at connection point '4'. The secondary side connection is made at connection point '3'. The common neutral connection is made at '2'.

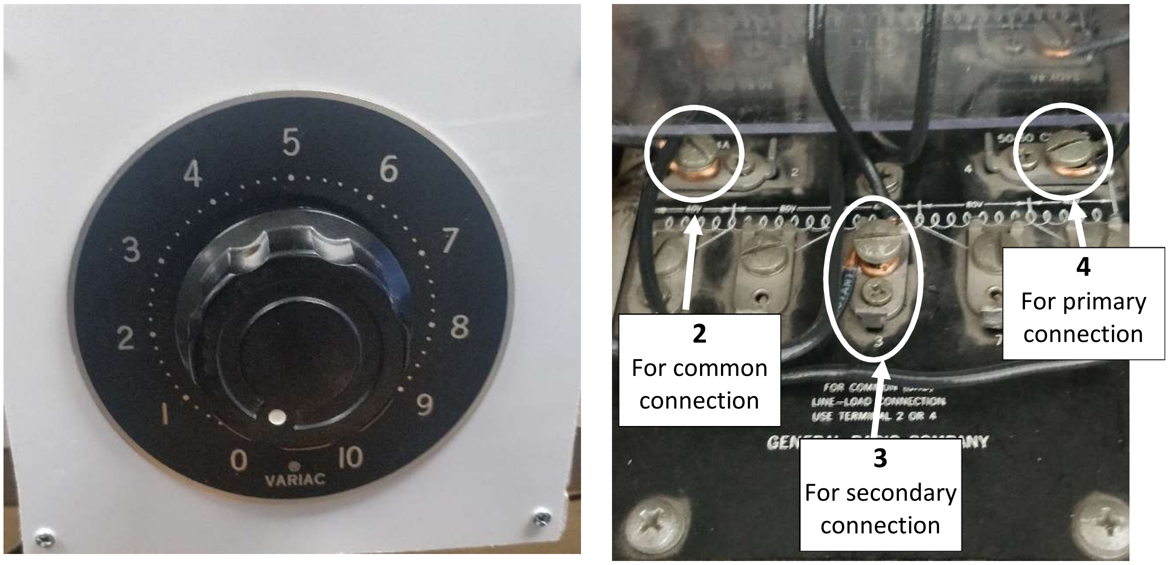


Figure 3.11 Variable autotransformer front view and rear view. Voltage can be adjusted with the knob

3.9. GE Industrial Circuit Breaker for Transformer Secondary Protection (I)

The secondary circuit is connected through a GE Industrial Circuit Breaker. The breaker was removed from the power simulator. The breaker can be turned on or off by the breaker handle. The tripping circuit of the breaker requires 125 VDC and 1 A current. When the breaker is tripped, the handle will move to position in between the on (handle all the way up) and off (handle all the way down). The breaker is reset by moving the handle from the tripped position to off position and then to on position.

Figure 3.12 GE Industrial circuit breaker used in the test bench

3.10. Load Connection Ports (J)

Resistive load can be connected to the Overcurrent Protection Relays Test Bench through the connection port. The connectors removed from the connection bench that was used to for this project have been utilized. The port has male and female connections for phases A, B and C, and the neutral, N as shown in Figure 3.13.

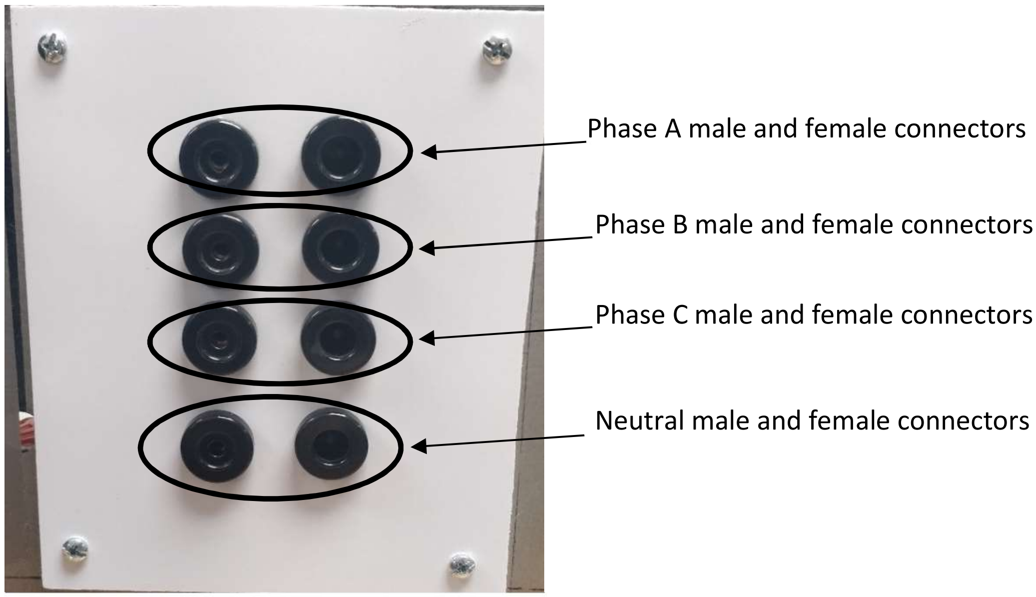


Figure 3.13 Load connection ports.

3.11. Full Wave Bridge Rectifier Circuit

In order to provide the appropriate DC voltage to operate the tripping mechanism of the industrial breaker (I) installed at the secondary of the variable autotransformer, a bridge rectifier circuit has been used. The schematic of the bridge rectifier circuit is presented in Figure 3.14.

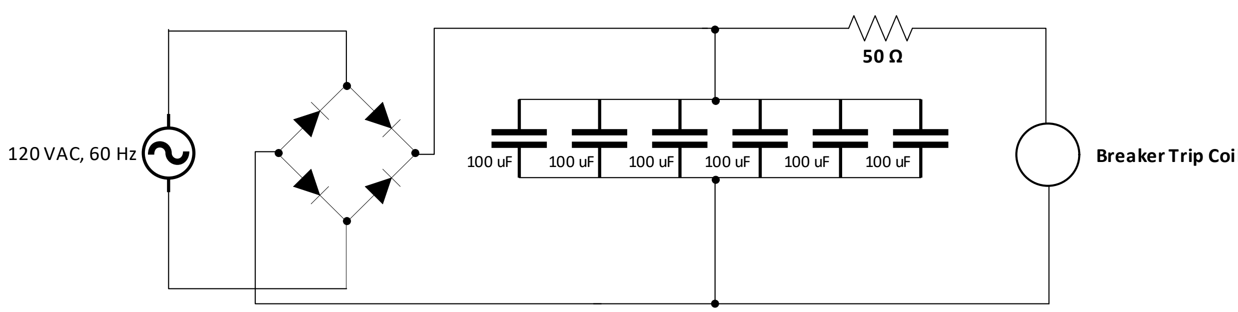


Figure 3.14 Schematic of bridge rectifier circuit for the industrial circuit breaker

The circuit employs a bridge rectifier diode for full rectification of single-phase AC voltage input. Six 100μF electrolytic capacitors are used for reducing the ripple voltage. A 50Ω resistance has been used to limit the output voltage to around 125 VDC. The value of resistor used was determined by noting the no load voltage of the rectifier circuit (nearly 175 VDC) and measuring the resistance of the tripping circuit of the breaker (around 125 Ω). Since the voltage is applied momentarily a resistance has been included to keep the maximum value of the voltage under 125 VDC.

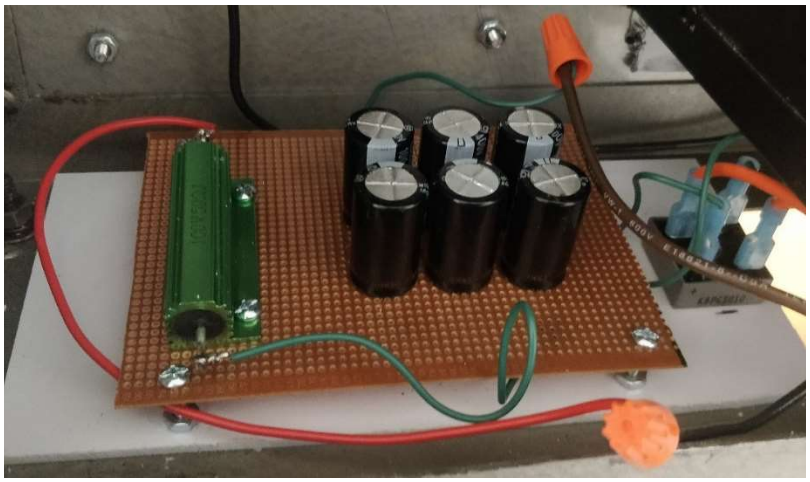


Figure 3.15 Full wave rectifier circuit used in the test bench

Chapter 4

SEL Feeder Protection Relay Communication and Monitoring Setup

The overall communication setup for SEL 751-A Feeder Protection Relays employed in the test bench for demonstrating the application of microprocessor-based overcurrent relay protection and SEL-387A Current Differential Relay that can be used for demonstrating the application of microprocessor-based differential current protection relay, is shown in Figure 4.1. The SEL-751A Feeder Protection Relays, used in the Overcurrent Protection Relays Test Bench, can be configured and monitored conveniently with ACSELERATOR QuickSet® SEL-5030 software. ACSELERATOR QuickSet® SEL-5030 software provides the options of using serial, network or modem connections. For the test bench, the relays are connected to the SEL-3351 Computing Platform by using serial ports on these devices. The Computing Platform is connected to Personal Computer (PC) with crossover ethernet cable. Communication between SEL relays and ACSELERATOR QuickSet® is done by serial to network conversion using SubstationSERVER.NET installed on the SEL-3351 Computing Platform. SubstationSERVER.NET supports various communication protocols. For this application, Port Server supported by SubstationSERVER.NET enables ACSELERATOR QuickSet® to access the serial ports on the computing platform through Ethernet connection.

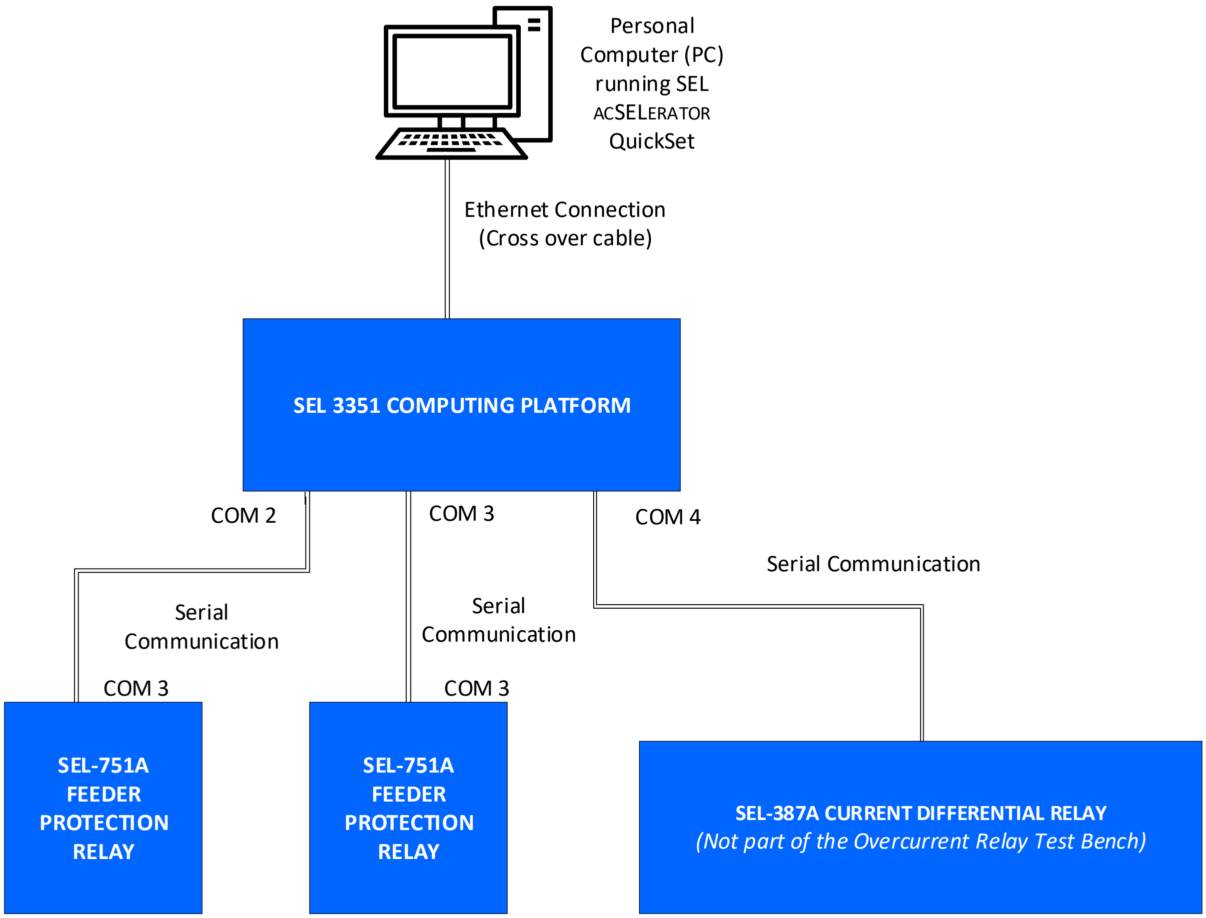


Figure 4.1. Communication set up for SEL microprocessor-based relays.

The procedure used in this project for configuring and monitoring SEL relays is outlined in figure 4.2.

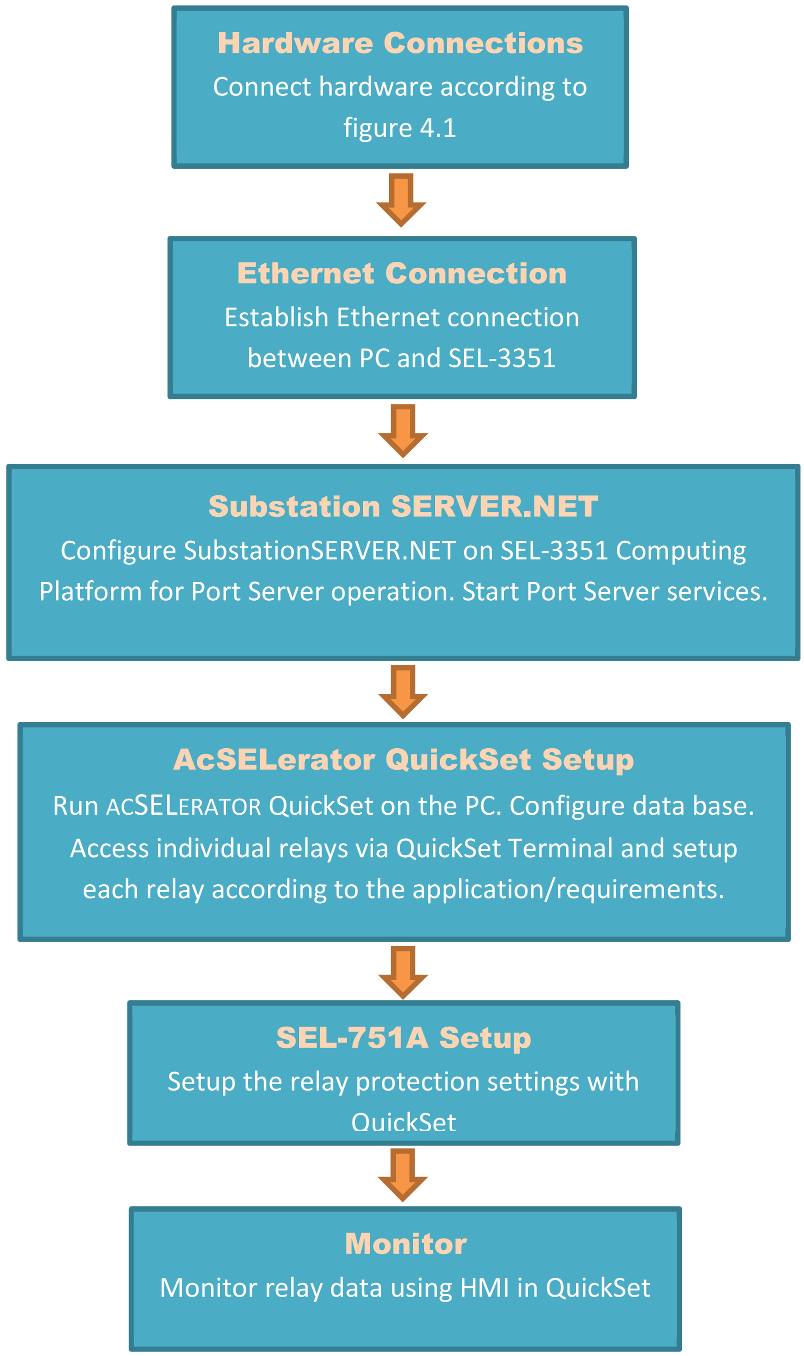


Figure 4.2. Procedure employed for configuring and monitoring SEL relays

4.1. Hardware Connections

The hardware connection is done as per Figure 4.1. Lab PC is connected to SEL-3351 Computing Platform via Ethernet crossover cable. SEL-751A Feeder Protection Relays are connected to SEL-3351 Computing Platform using serial ports on these devices and SEL serial cables. COM port 3 on SEL-751A has been utilized. On the Computing Platform, COM ports on the rear side have been utilized. Computing Platform has 16 serial ports for connecting devices. For the overcurrent relay test bench, COM2 has been configured for connecting relay used for transformer primary protection. COM 3 has been connected with the relay that is employed for feeder (load) protection. COM4 has been configured to connect SEL-387A Current Differential Relay which can be used in the test bench proposed for demonstrating current differential protection relay (Chapter 5).

4.2. Establishing Ethernet Connection between PC and SEL-3351 Computing Platform

After the hardware is connected, Ethernet connection has to be established between the lab PC and SEL-3351 Computing Platform. For this purpose, IP addresses have to be assigned to both the PC and the Computing Platform. This is first done for the lab PC. As both the lab PC and the Computing Platform are running Windows XP, the procedure is similar. The steps are outlined as follows.

1) From the main desktop of lab PC, access My Network Places by following, Start Menu→All Programs→My Network Places

Figure 4.3 Accessing Network Places

2) Click View network connections (Figure 4.4)

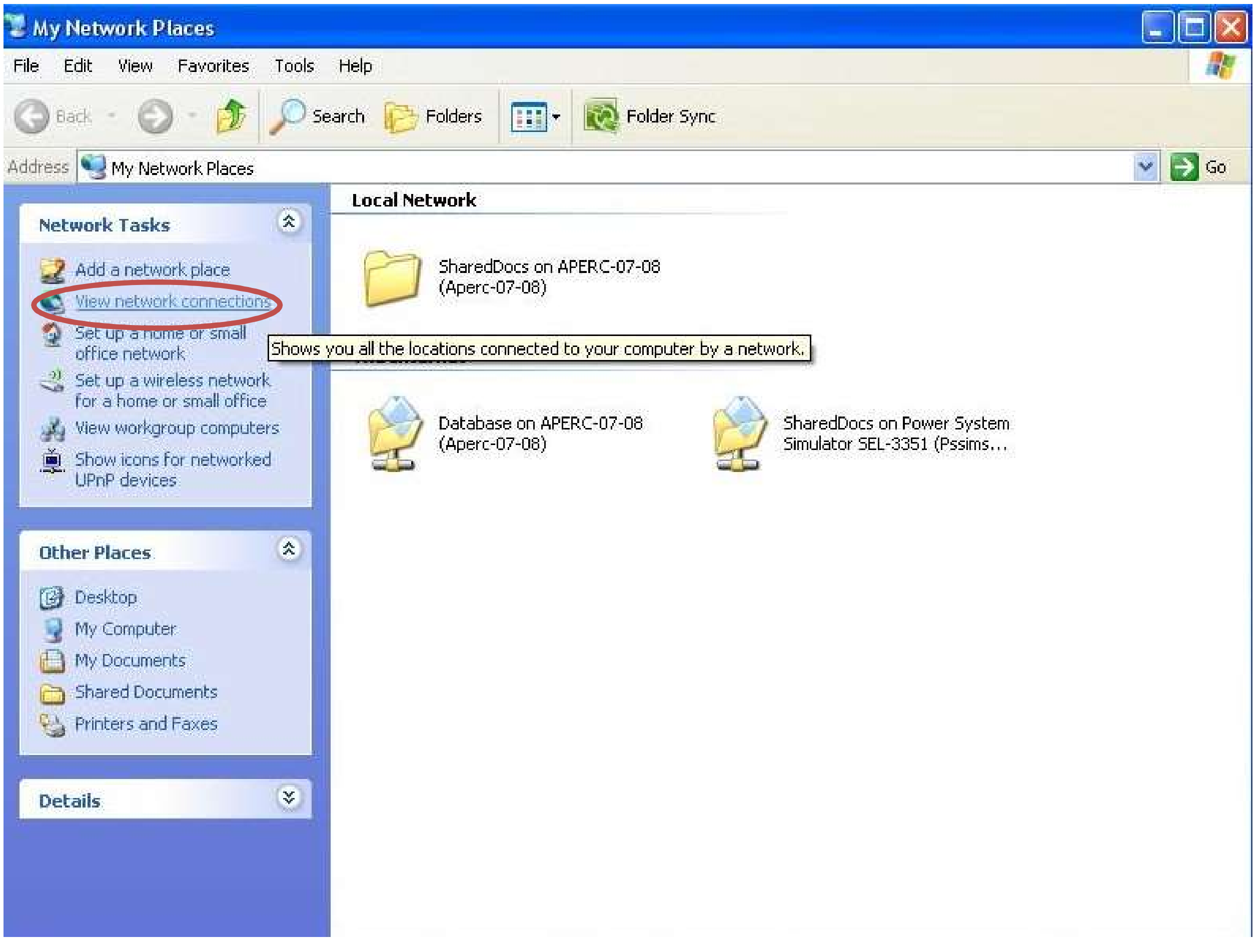


Figure 4.4 Network Connections

3) Right Click on Local Area Connection and select Properties

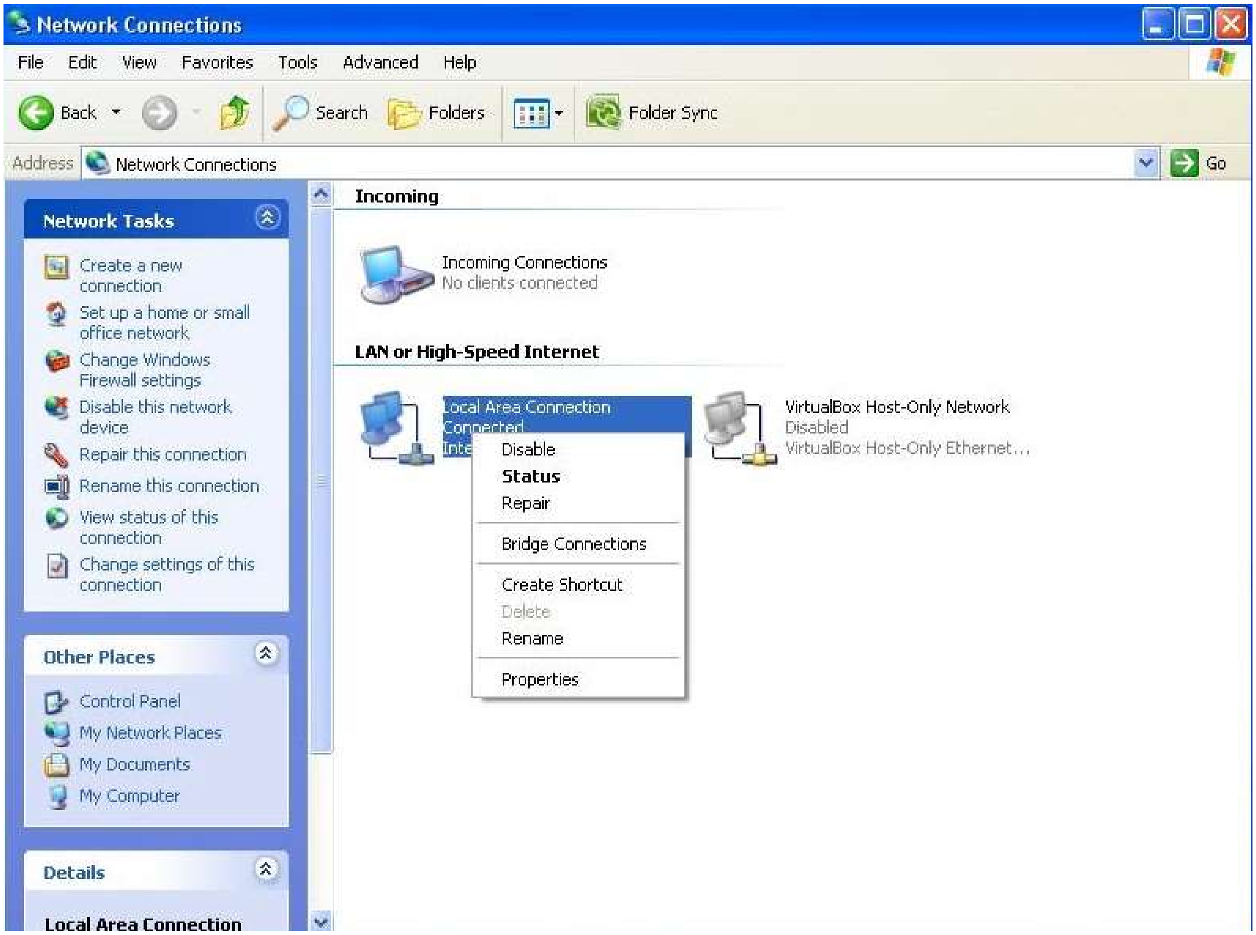


Figure 4.5 Network Properties

4) From the window that appears, select Internet Protocol (TCP/IP). A window will appear. Enter IP address as shown

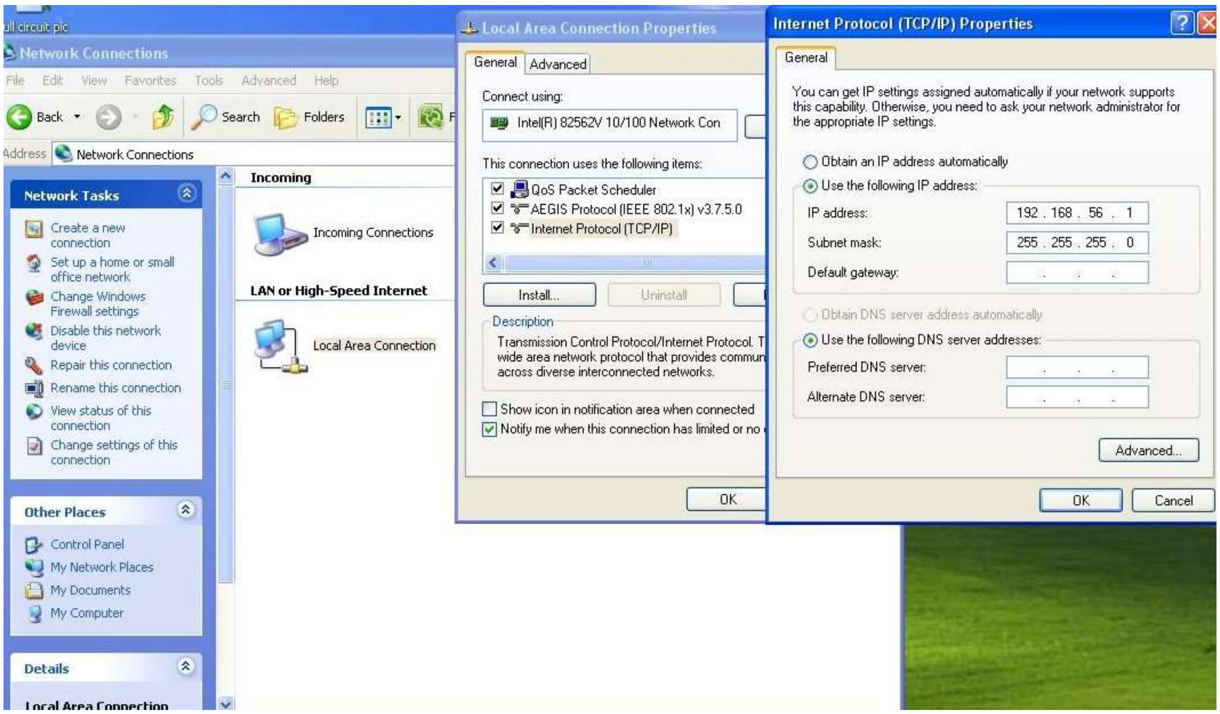


Figure 4.6 Accessing IP properties

The IP address settings used for Lab PC and SEL-3351 Computing Platform are given in the following Table 4.1.

Table 4.1 IP properties used for PC with QuickSet and SEL-3351 Computing Platform

PC	
IP Address	192.168.56.1
Subnet Mask	255.255.255.0
Default Gateway	. . . . (left blank)
SEL-3351 Computing Platform	
IP Address	192.168.56.2
Subnet Mask	255.255.255.0
Default Gateway	. . . . (left blank)

Important- *First three fields of the IP address should match. The last number in the IP address should be different for PC and Computing Platform.*

The procedure described above can be used to assign IP address to the SEL-3351 Computing Platform. Once the IP address are set, the connection between the PC and Computing Platform can be checked by issuing a ping in command prompt from either machine. If the PC is used to verify the connection then Computing Platform should be pinged (ping IP address of Computing Platform i.e. ping 192.168.56.2).

4.3. SubstationSERVER.NET Setup

Once the Ethernet connection has been established, the communication of SEL relays with PC running ACSELERATOR QuickSet software has to be established. This can be done using SubstationSERVER.NET software on SEL-3351 Computing Platform. SubstationSERVER.NET provides protocol translation, SUBNET [5].

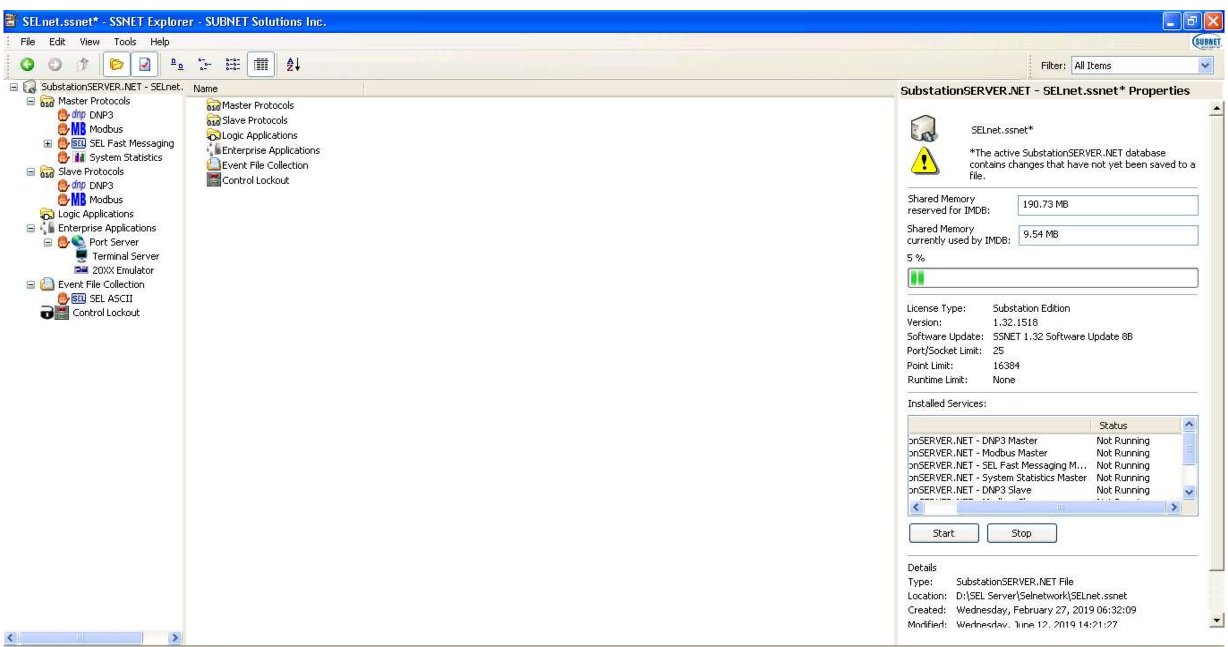


Figure 4.7 SubstationSERVER.NET

The manufacturer's guide listed at SUBNET [5] details capabilities of the software. Here only those aspects which are pertinent to this project are described. The software can be launched from the software's icon on the desktop of SEL-3351 Computing Platform.

When the software is launched a screen similar to the one indicated in Figure 4.7 will appear. The left pane shows the various protocols supported by SubstationSERVER.NET. The center pane lists the devices and ports configured for each supported protocol. New ports can be configured on this pane. The right side shows the properties associated with a port (i.e. Ethernet port or serial COM port) when the port is selected for a particular protocol listed on the left pane.

Some of the pertinent protocols and applications supported by SubstationSERVER.NET installed on the Computing Platform are listed in the Table 4.2.

Table 4.2 Protocols supported by SubstationSERVER.NET installed on the Computing Platform

Master Protocols	DNP3 Modbus SEL Fast Messaging (For SEL devices)
Slave Protocols	DNP3 Modbus
Enterprise Applications	Port Server
Event File Collection	SEL ASCII

Modbus or DNP3 protocols are widely used in industry for connecting field devices like relays to third party applications. However, for this project the SEL-751A relays, used in the Overcurrent Protection Relays Test Bench, have been configured to work with SEL ACSELERATOR QuickSet. For this purpose, Port Server under Enterprise Applications in SubstationSERVER.NET can be utilized to connect SEL relays with ACSELERATOR QuickSet. The COM ports, which have to be accessed (ports where relays are connected), need to be defined and configured. The configuration of COM port involves entering information such as baud rate, byte size, parity and stop bits. To demonstrate the detailed configuration of serial COM port on the Computing Platform for communication with QuickSet software, the process for serial port 5 is shown. For this example, a spare SEL-751A relay connected to COM5 port is used, which is not a part of the overcurrent relay testing bench. COM2 (for SEL-751A Feeder Protection Relay used for primary side protection of autotransformer), COM3 (for SEL-751A Feeder Protection Relay used for load or feeder protection), and COM4 (for SEL-387A for current differential protection) have been configured in the same manner as illustrated below.

1) Launch SubstationSERVER.NET from its desktop icon on the Computing Platform

Figure 4.8 Computing Platform Desktop with SSNET Explorer icon

2) Make sure that all services are stopped. This can be checked on the right-side pane as shown in figure 4.9. If services are running then these have to be stopped. This can be done by right clicking on SubstationSERVER.NET and selecting Stop All Services as shown in figure 4.10. This step is important otherwise the software does not allow configuration of new port.

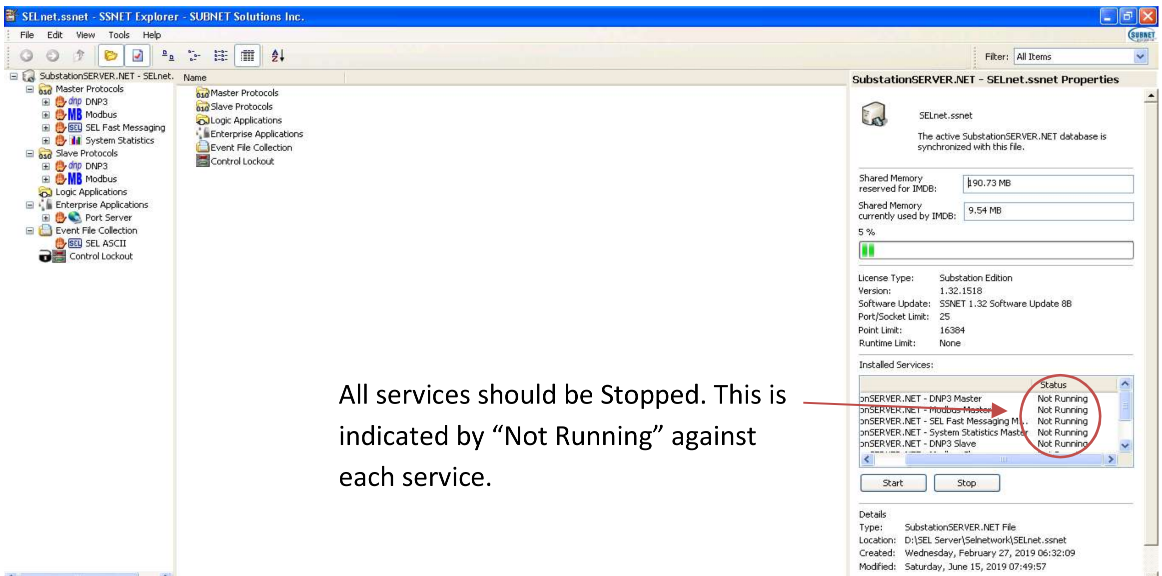


Figure 4.9 Main screen when SSNET Explorer is launched. Status of various is indicated as shown.

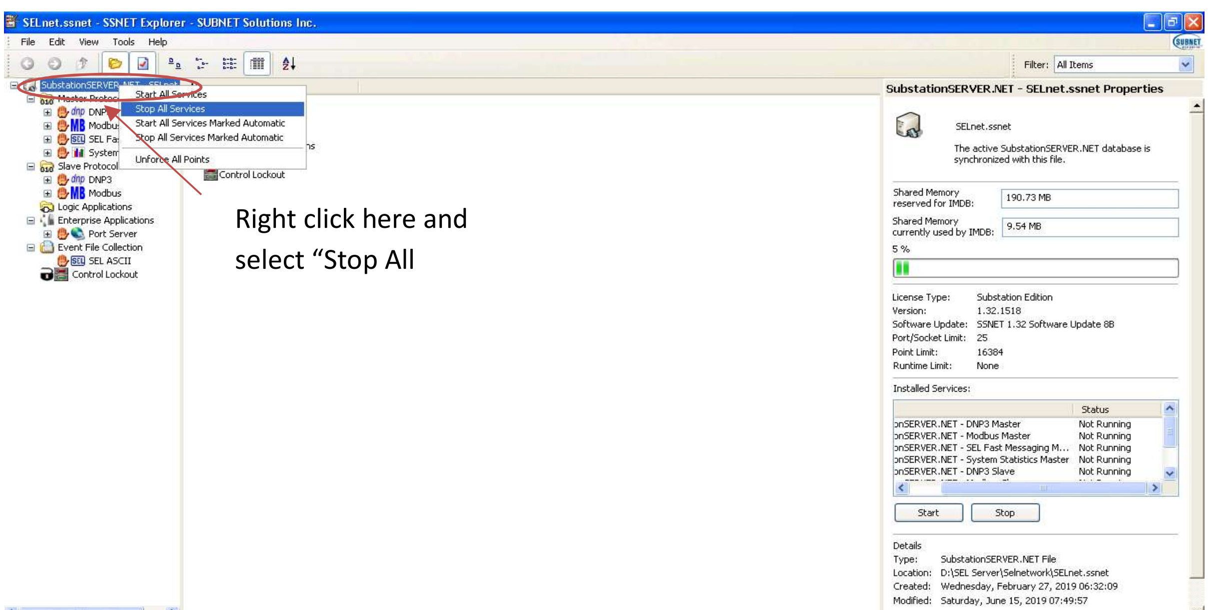


Figure 4.10 Stopping all services.

3) The next step is to define a new COM port under Enterprise Application → Port Server → Terminal Server. This can be done directly, however, in case of SEL devices it is more convenient to use Online Relay Wizard under SEL Fast Messaging. From the left pane select, Substation SERVER.NET-SELnet.ssnet*→ Master Protocols → SEL Fast Messaging. Right Click anywhere on the center pane and select New→Serial Connection as shown in Figure 4.11.

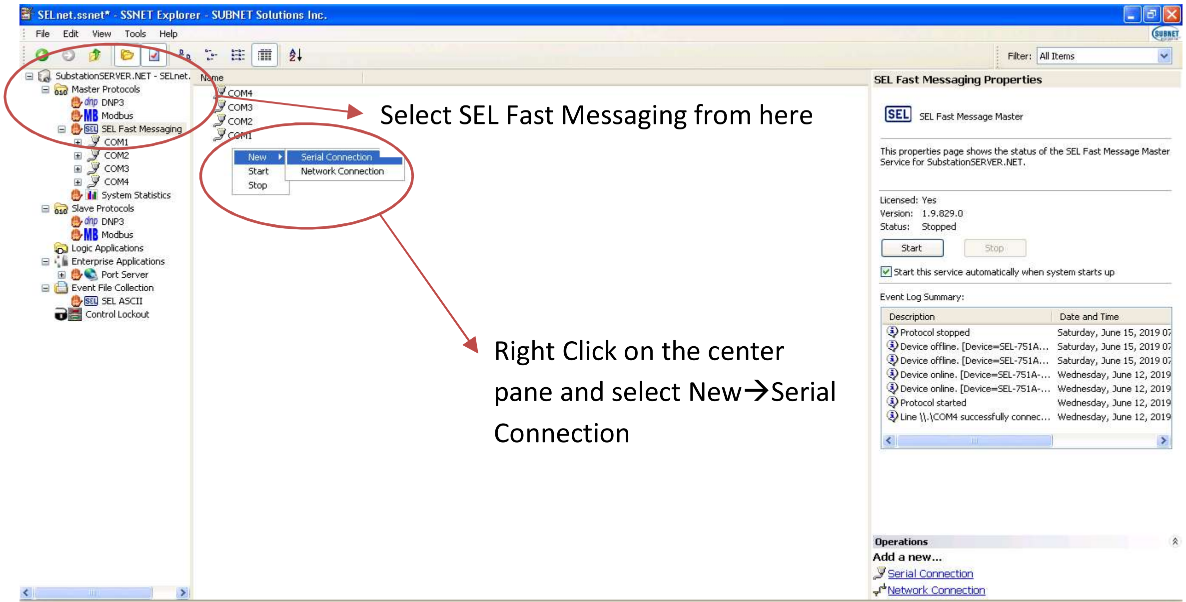


Figure 4.11 Defining new COM port under SEL Fast Messaging

4) A new COM is given a default name of COM1. This name should be changed according to the port being used to connect the device with the Computing Platform. For this example, we are using serial port 5 so we name it COM5 as shown in Figure 4.12.

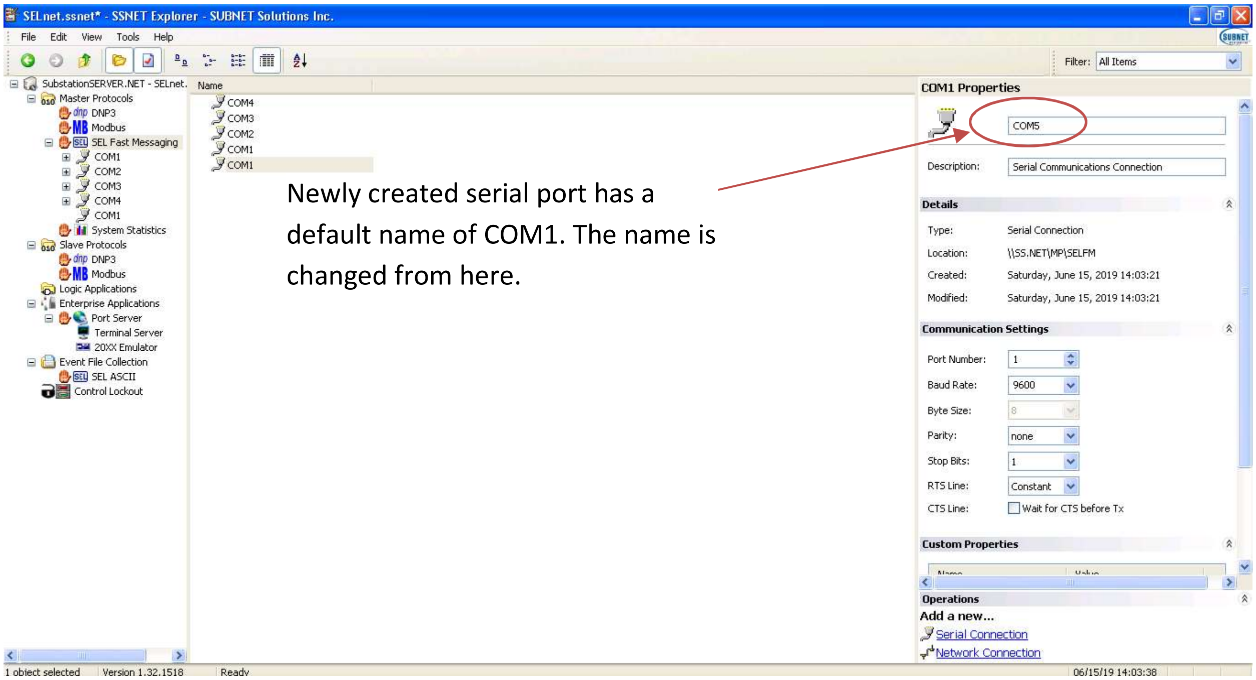


Figure 4.12 Renaming serial COM port

5) Click on the name of newly created COM port. This will open properties of COM port on the right pane. It is important to know the baud rate, byte size, parity and stop bits. These settings can be checked against default settings described in SEL device manuals or directly checked from a device using front panel keys. For this example, a SEL-751A with following properties is configured.

Table 4.3 Serial Properties for SEL-751A

Property	Description	Value/Setting used in this example
Port Number	This is usually number of the serial port on the Computing Platform. We are configuring COM 5. So, we select 5 here.	**5**
Baud Rate	This is baud of the device (relay) being connected.	**9600**
Byte Size	Byte size selected for the relay	**8**
Parity	Parity being used by the device for serial communication	**none**
Byte Size	Byte Size being used by the device for serial communication	**1**
RTS Line	Request to Send	**Constant**
CTS Line	Clear to Send	**Check**

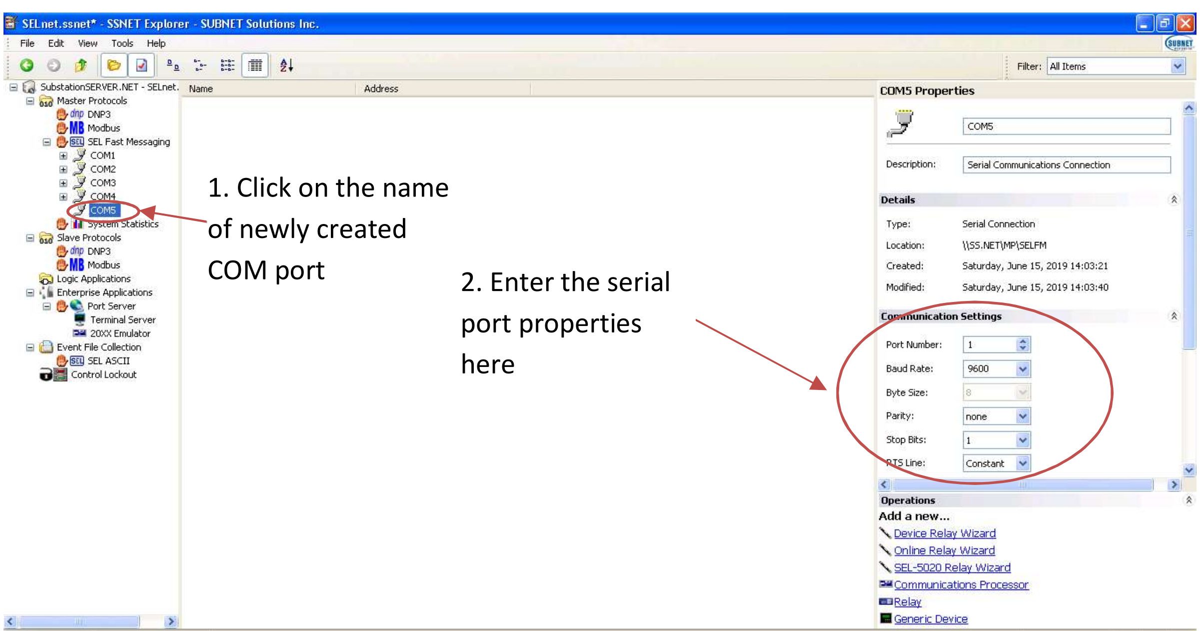


Figure 4.13 COM port configuration

6) After configuring the serial COM properties, Online Relay Wizard (on the lower side of right pane) has to be launched. This will open a window as shown in Figure 4.14. Enter level 1 password of relay being connected and click Connect.

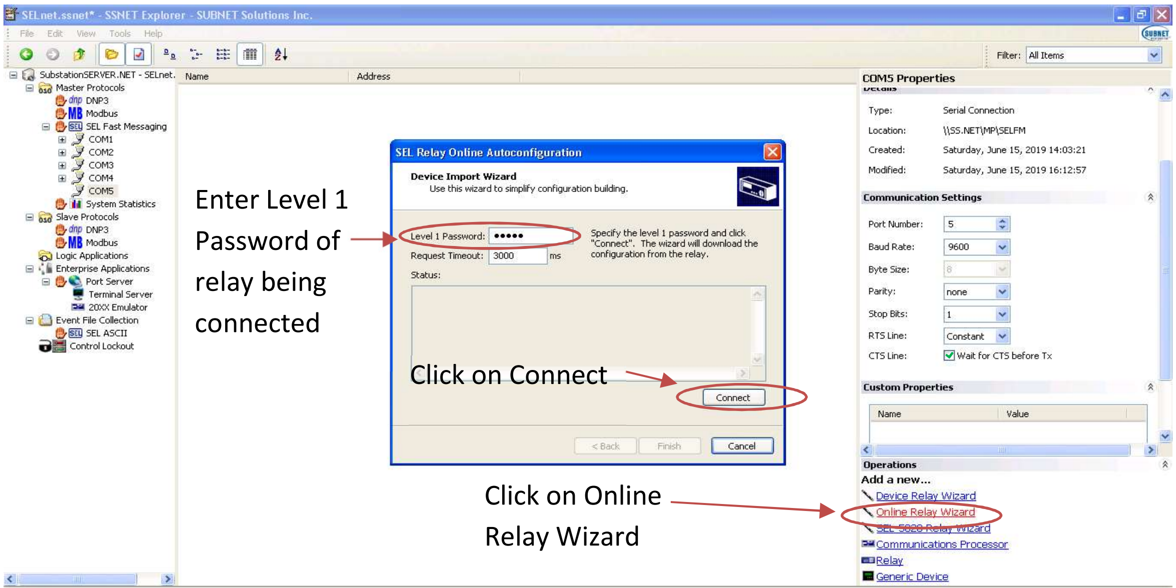


Figure 4.14 Starting the Online Relay Wizard

Once autoconfiguration is complete, click **Finish**.

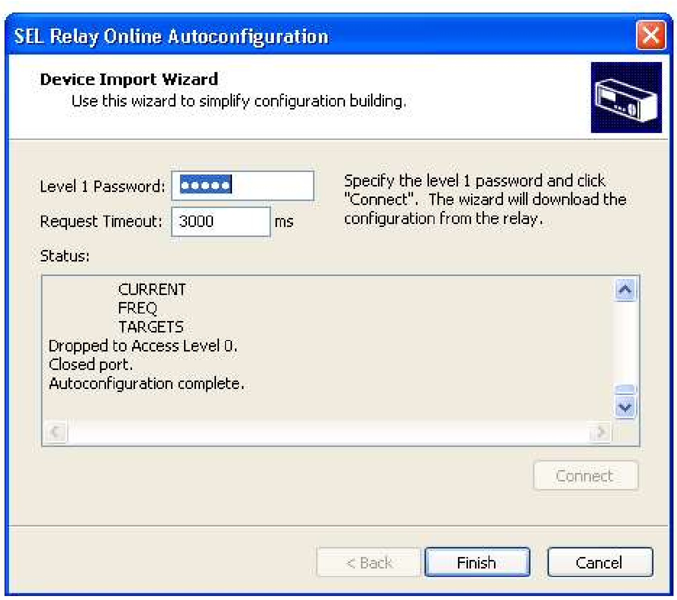


Figure 4.15 Successful completion of auto configuration

7) Access Terminal Server from the left pane by selecting,
Substation SERVER.NET-SELnet.ssnet* → Enterprise Applications → Port Server → Terminal Server

Right click on the center pane and select New → Serial Port.

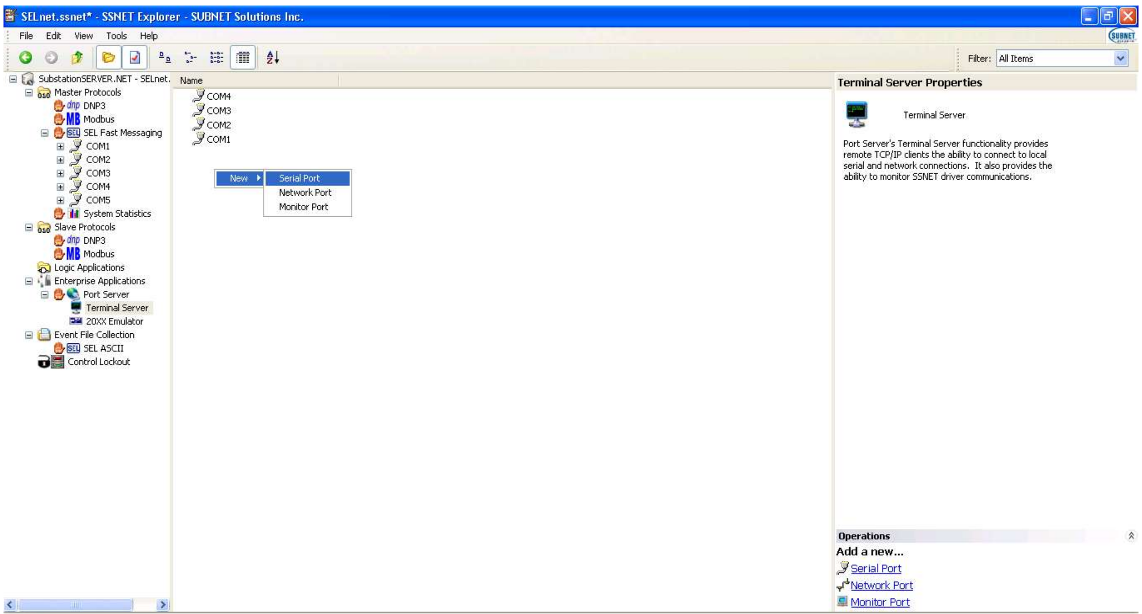


Figure 4.16 Defining serial COM port under Terminal Server

8) Rename the newly created COM port to COM5 (same name as given in step 4). See Figure 4.17.

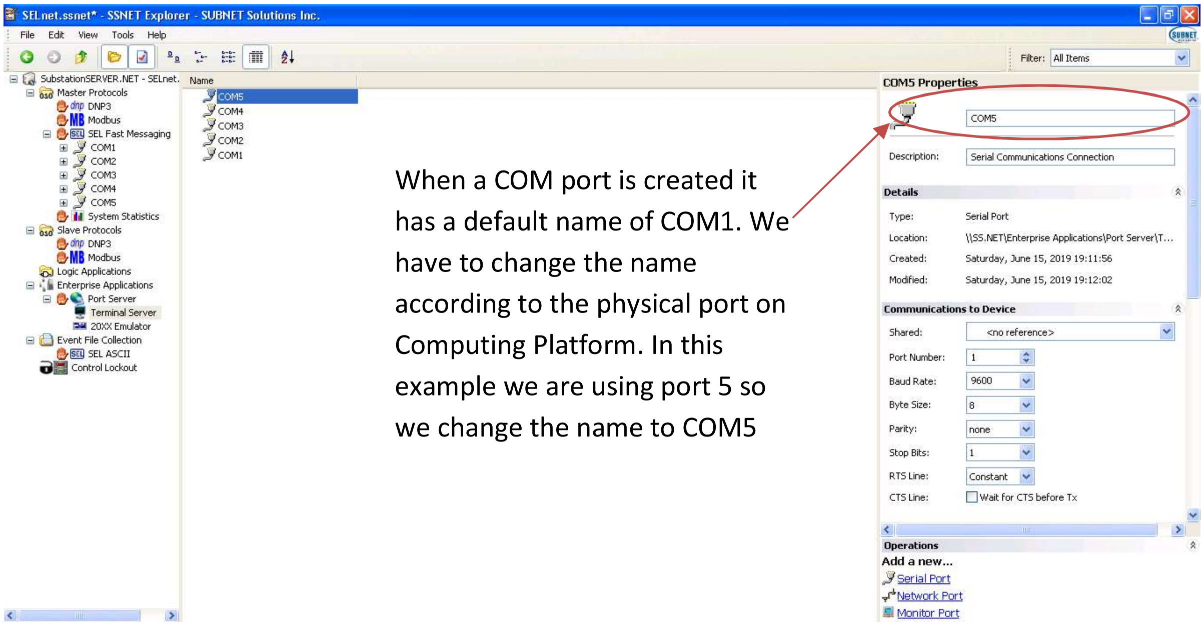


Figure 4.17 Changing the name of newly defined COM port

9) Under COM properties (right pane), following parameters are set. These are indicated in Figure 4.18 and 4.19. The properties not described in the Table 4.4, are left at default settings.

Table 4.4 Configuration of COM properties

COM Properties	Settings	Description	Setting/Value Used
Communications to Device	**Shared**	This option will import serial port settings directly instead of entering them manually. Since we have already imported device setting by defining COM5 under SEL Fast Messaging (Steps 1-6), we can share serial port settings by selecting COM5. This will link COM5 defined under Terminal Server to COM5 defined under SEL Fast Messaging	**COM5**
Local Network Settings	Address	Enter the IP address of Computing Platform	**192.168.56.2**
	Transport	Given by default	**TCP/IP**
	Port (SEL Maint)	Disabled by setting equal to zero	**0**
	Port (Direct)	TCP direct port setting. We are using a format 100xx, where xx represents the port number. In our example xx=05	**10005**

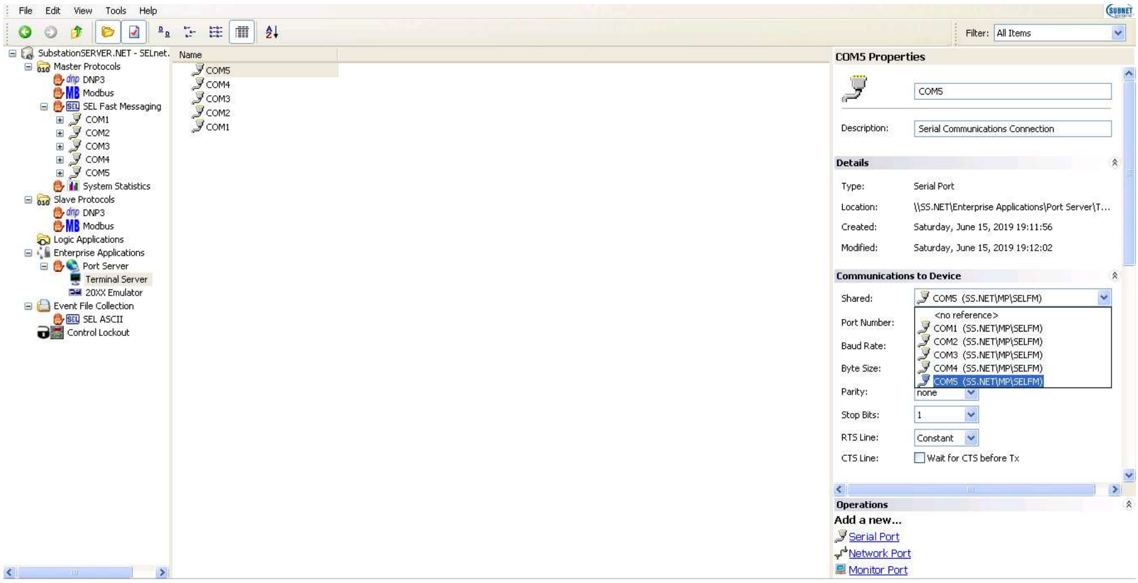


Figure 4.18 Selecting COM port from Shared drop-down menu.

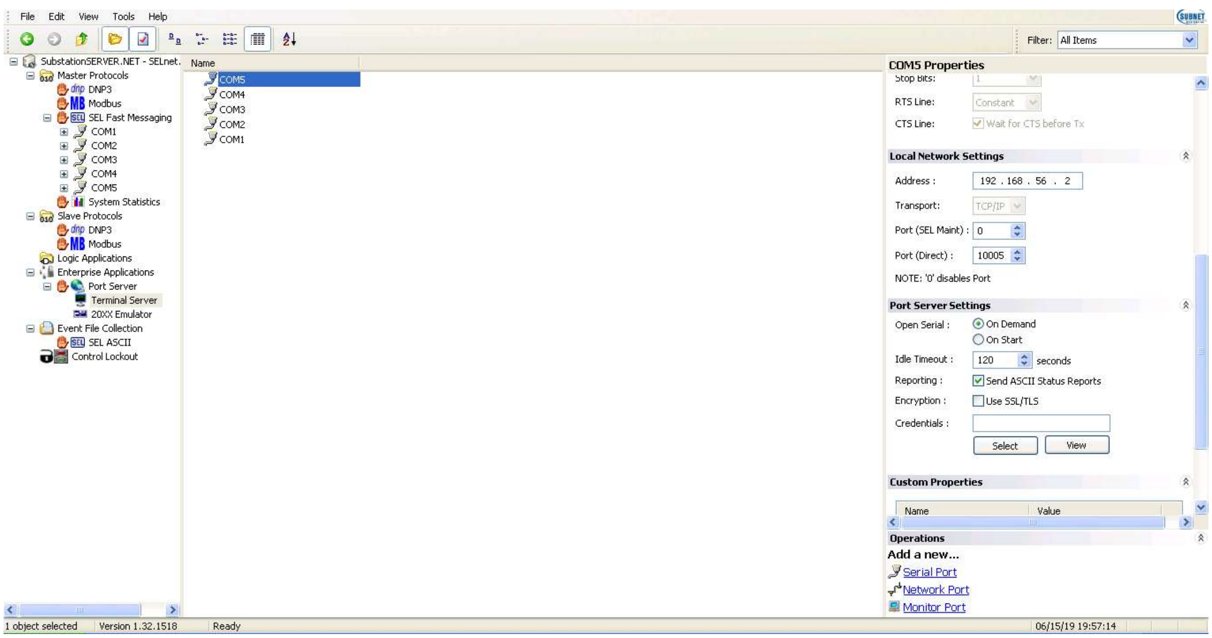


Figure 4.19 Setting network properties

10) Once the settings have been configured, Port Server services have to be started. This can be done by right clicking on the Port Server (Substation SERVER.NET-SELnet.ssnet* → Enterprise Applications → Port Server). The services can also be started by clicking "Start" on the right-side pane. It is also convenient to check "Start this server automatically when system starts up" option. This is shown in Figure 4.20.

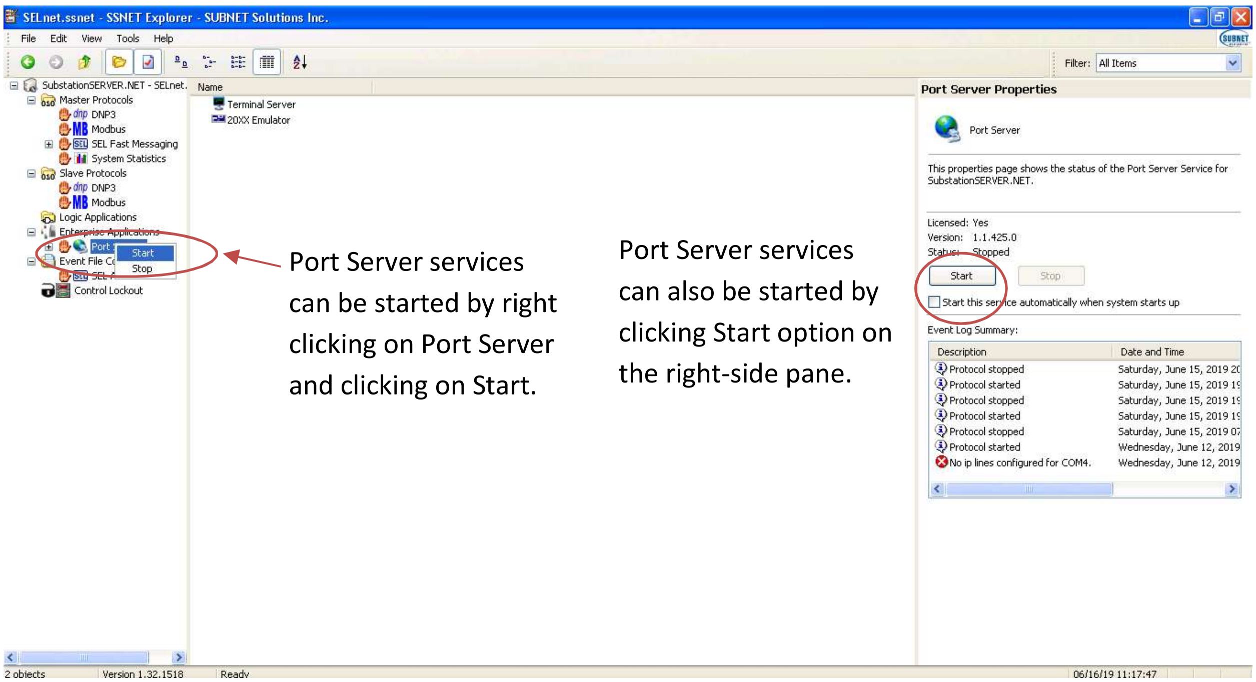


Figure 4.20 Start Port Server services

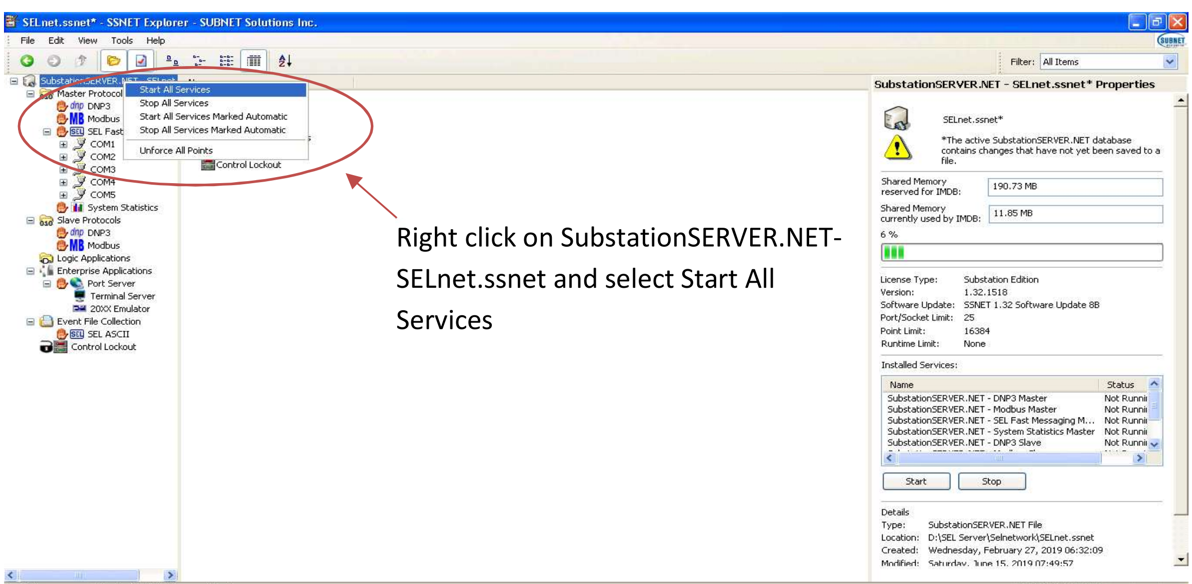


Figure 4.21 Another way of starting services.

Click **OK** if there is any message. The status of various services running is visible on the right-side pane. This is shown in figure 4.22. The aim is to start Port Services.

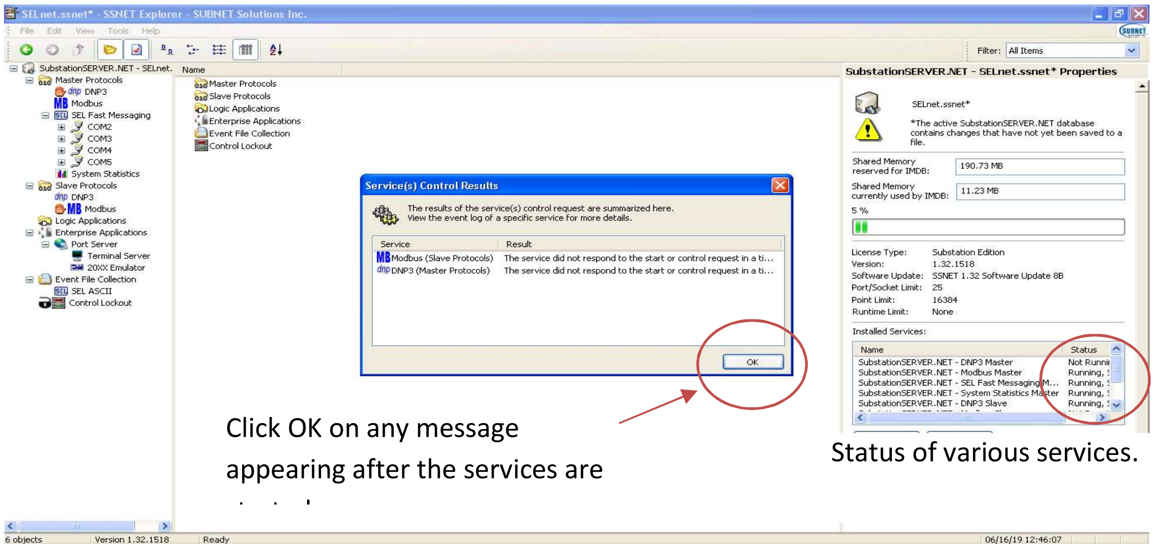


Figure 4.22 Services running.

4.4. ACSELERATOR QuickSet® Settings

Once configuration settings have been completed on the Computing Platform, configuration settings in SEL ACSELERATOR QuickSet® SEL-5030 software, running on overcurrent relay test bench PC, have to be completed. At this point it is essential that Port Server services in SubstationSERVER.NET on the Computing Platform should be running, otherwise ACSELERATOR QuickSet will not be able to communicate with the relays.

4.4.1. ACSELERATOR QuickSet Communication Settings (Direct Communication)

The steps required to configure settings for establishing communication between AcSELerator QuickSet and relays connected with computing platform are described below.

1) Launch ACSELERATOR QuickSet from start → All Programs → SEL Applications → ACSELERATOR QuickSet.

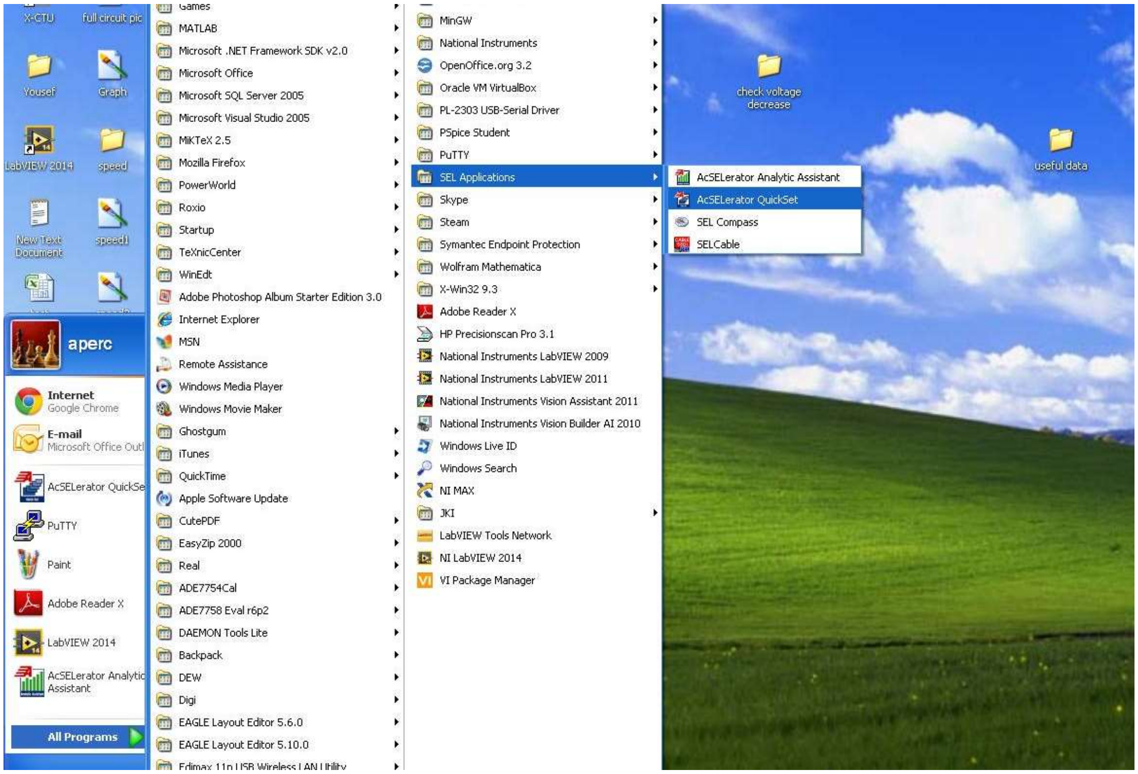


Figure 4.23 Launching QuickSet

2) From the main menu go to Communications → Parameters as shown in Figure 4.24.

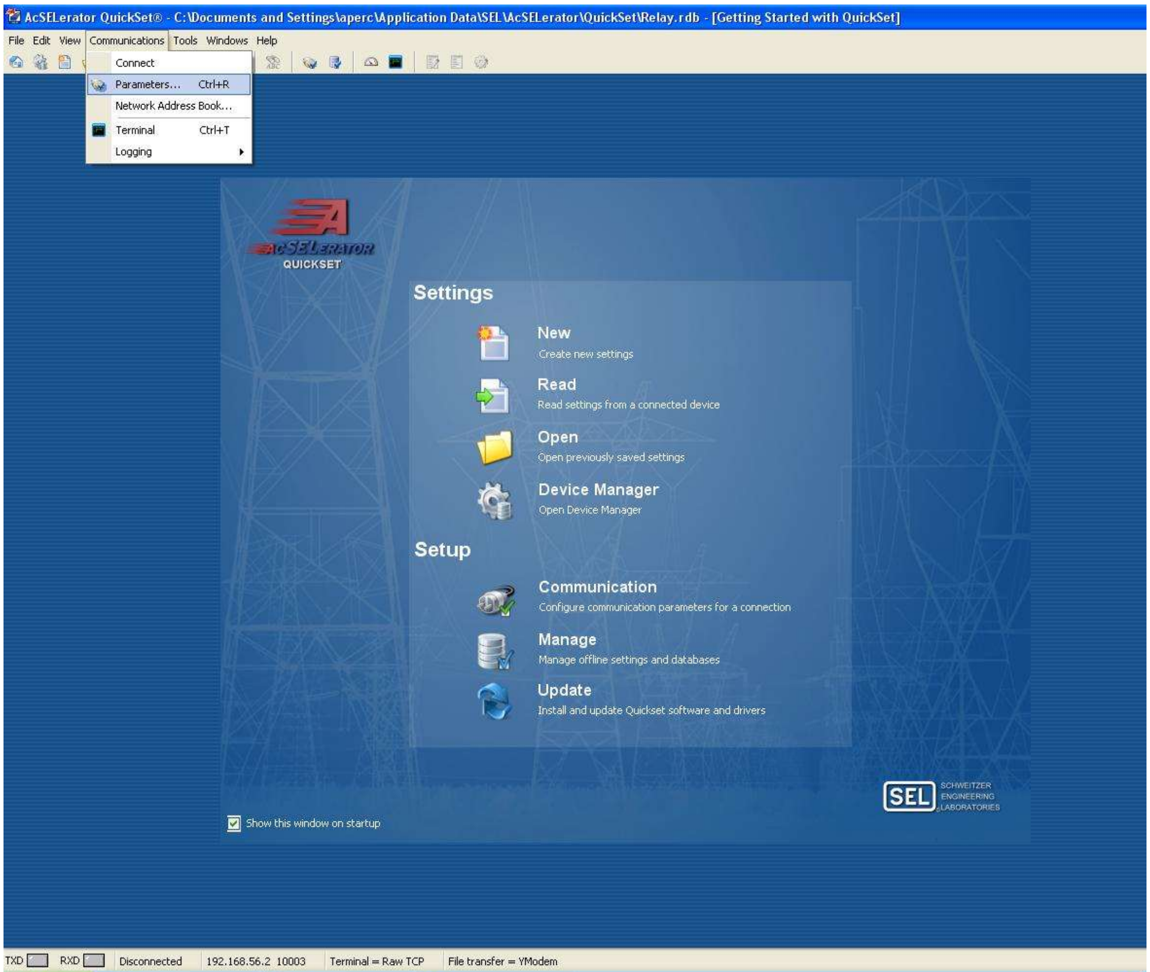
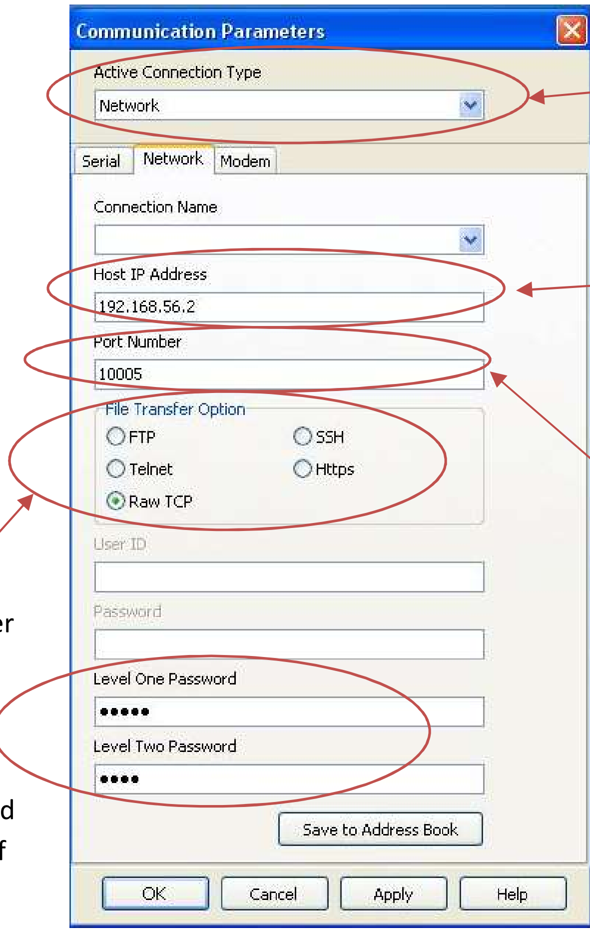


Figure 4.24 Accessing communication parameters from the main menu.

3) Use the following setting in the Communication Parameters to configure COM5 port on Computing Platform as shown in Figure 4.25.



Select Active Connection Type **Network**

In Host IP Address enter the IP address of the Computing Platform. We have set the IP address of Computing Platform as **192.168.56.2**

The format used for port number is 100xx. Since we are configuring COM5 so Port Number is **10005**

Select File Transfer Option **Raw TCP**

These are Level One and Level Two passwords of SEL devices. Usually default password are provided and don't have to be entered. For SEL-751A default Level One password is **OTTER** and Level Two password is **TAIL**

Figure 4.25 Setting communication parameters in QuickSet

4) Once the communication between relay and acSELerator QuickSet is successfully established, the lower portion will state the condition Connected and also list the communication parameters. To ensure that successful communication open Terminal by clicking on its icon on the main menu. When terminal window is opened, and = sign will appear. Type ACC. If communication is established, the Terminal will prompt for Level One password of device (in this case SEL 751-A relay). This is shown in Figure 4.26.

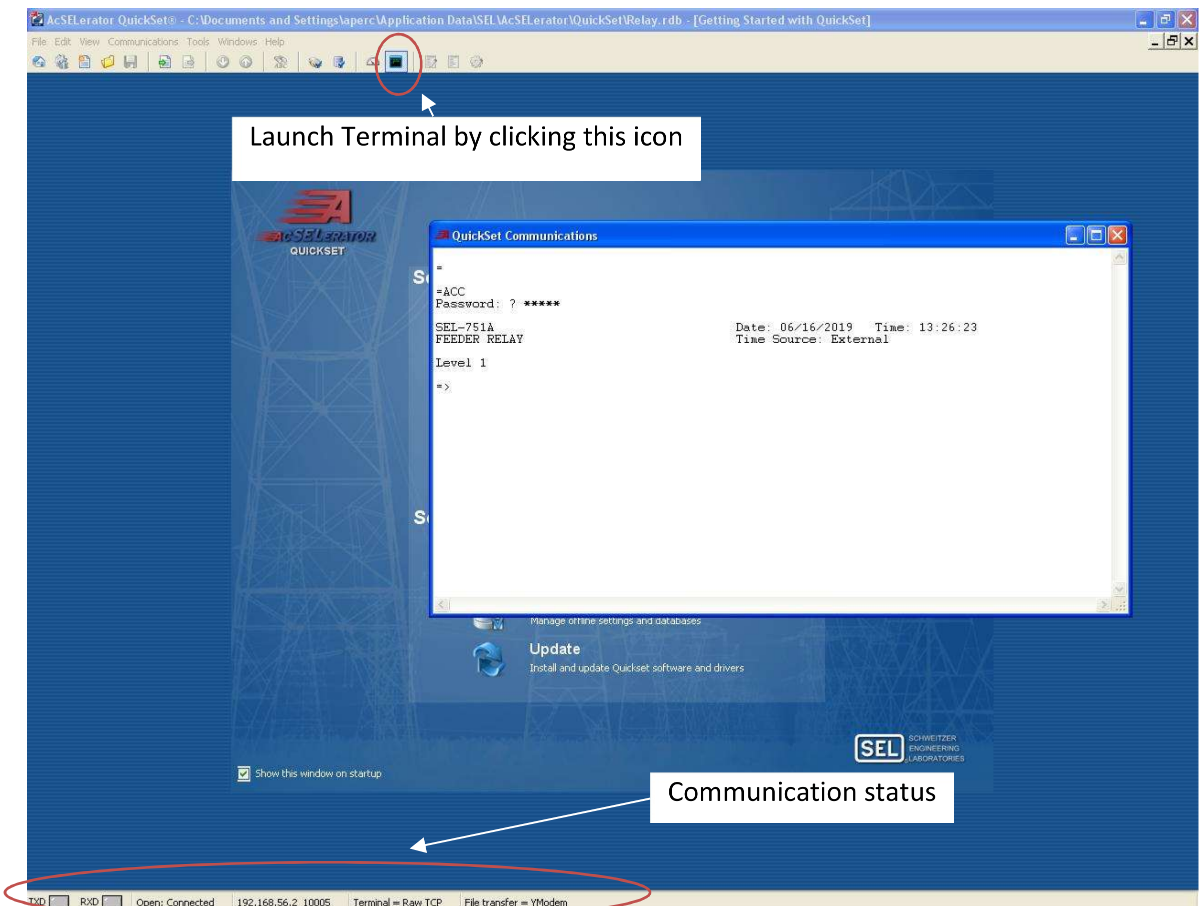


Figure 4.26 Confirming successful communication in QuickSet

4.4.2. ACSELERATOR QuickSet® Communication Settings (Through Database)

Section 4.4.1 described the process of establishing direct communication with a SEL device. It is, however, more convenient to use ACSELERATOR QuickSet Database to configure a device. This allows for configuring different devices and save the individual settings of these settings. The default database is Relay.rdb. Once the settings are saved in the database, then it becomes very easy to connect to a device. The process is shown as follows.

1) From the main menu select Tools → Device Manager → Devices. The Device Manager option is also available on the main display when ACSELERATOR QuickSet is first launched. A window shown in Figure 4.27 will appear. In the field where password is required, enter the password of the database. The password of the default database in QuickSet installed in the lab PC is aperc.

Figure 4.27 Access to ACSELERATOR Database

2) When the database is opened the folders defined in the database are shown on the left pane under Connection Explorer. Since a SEL-751A Feeder Protection Relay is being added, the configuration is added in Overcurrent Relay folder. This is done by right clicking on the folder name and then selecting Add and then Device as shown in Figure 4.28. A window, shown in figure 4.29, will appear. Select SEL-751A.

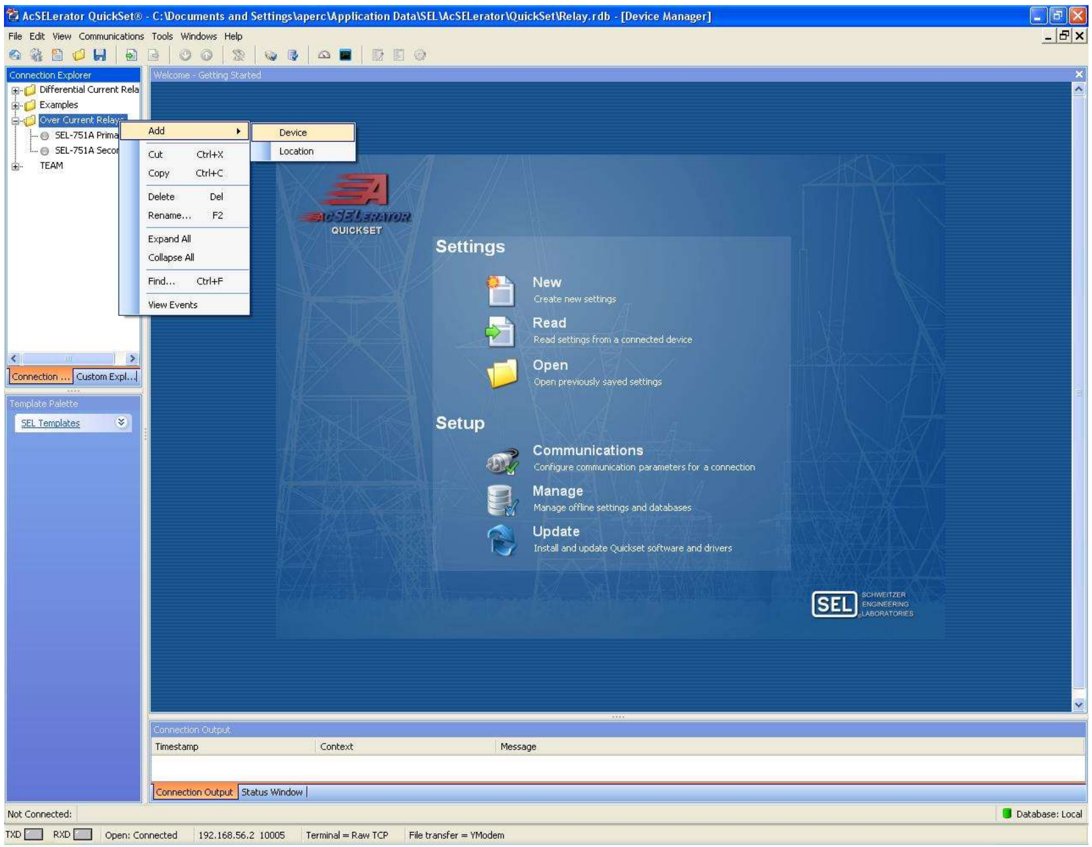


Figure 4.28 Adding a new device in the database

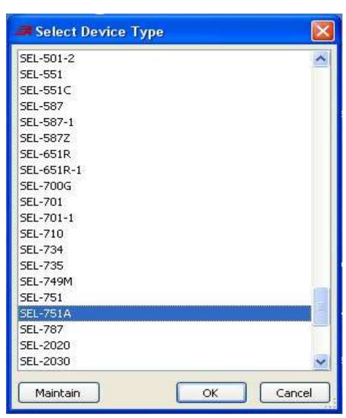


Figure 4.29 Selecting Device Type

3) Once the device is selected, the name of device is added under folder tree. Clicking on the device name will open a new window where properties of the device can be configured. This is shown in Figure 4.30. Select Connection and then click on Edit on the lower right corner.

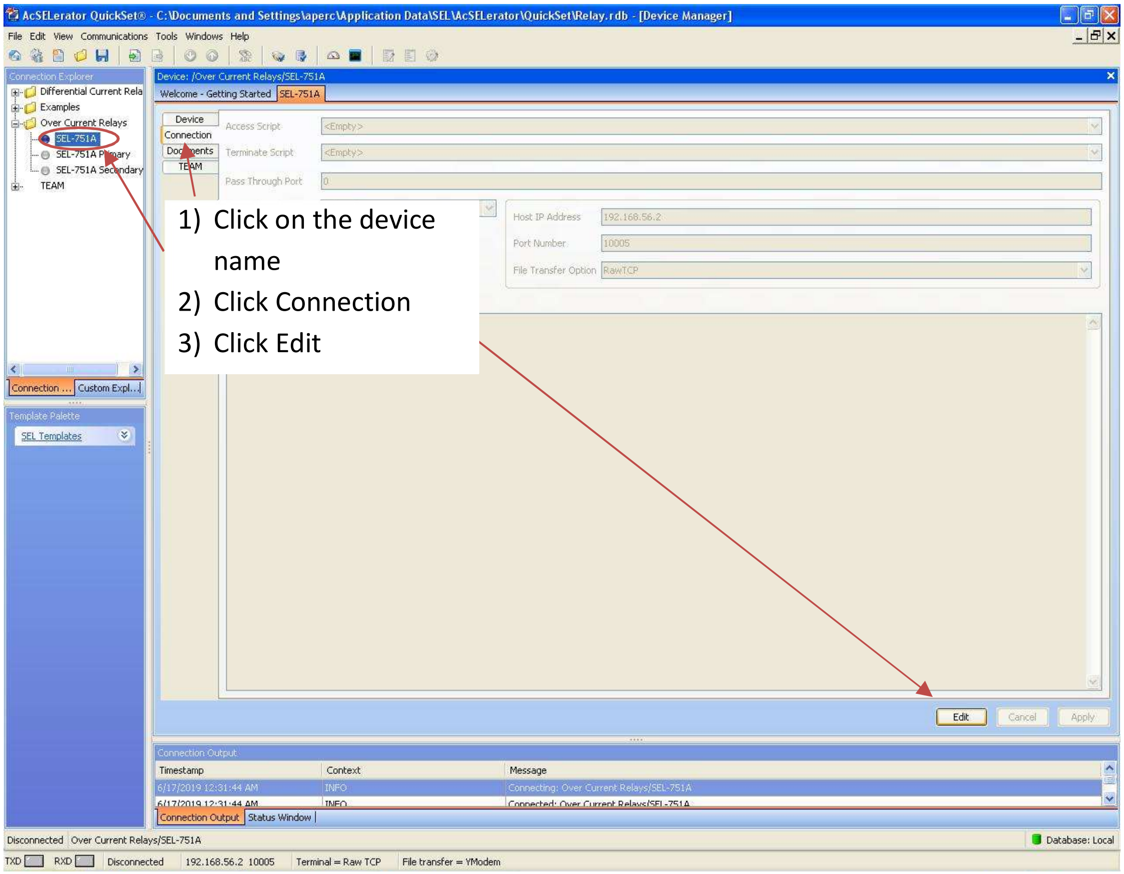


Figure 4.30 Accessing device properties

4) Enter the communication properties as shown in Figure 4.31

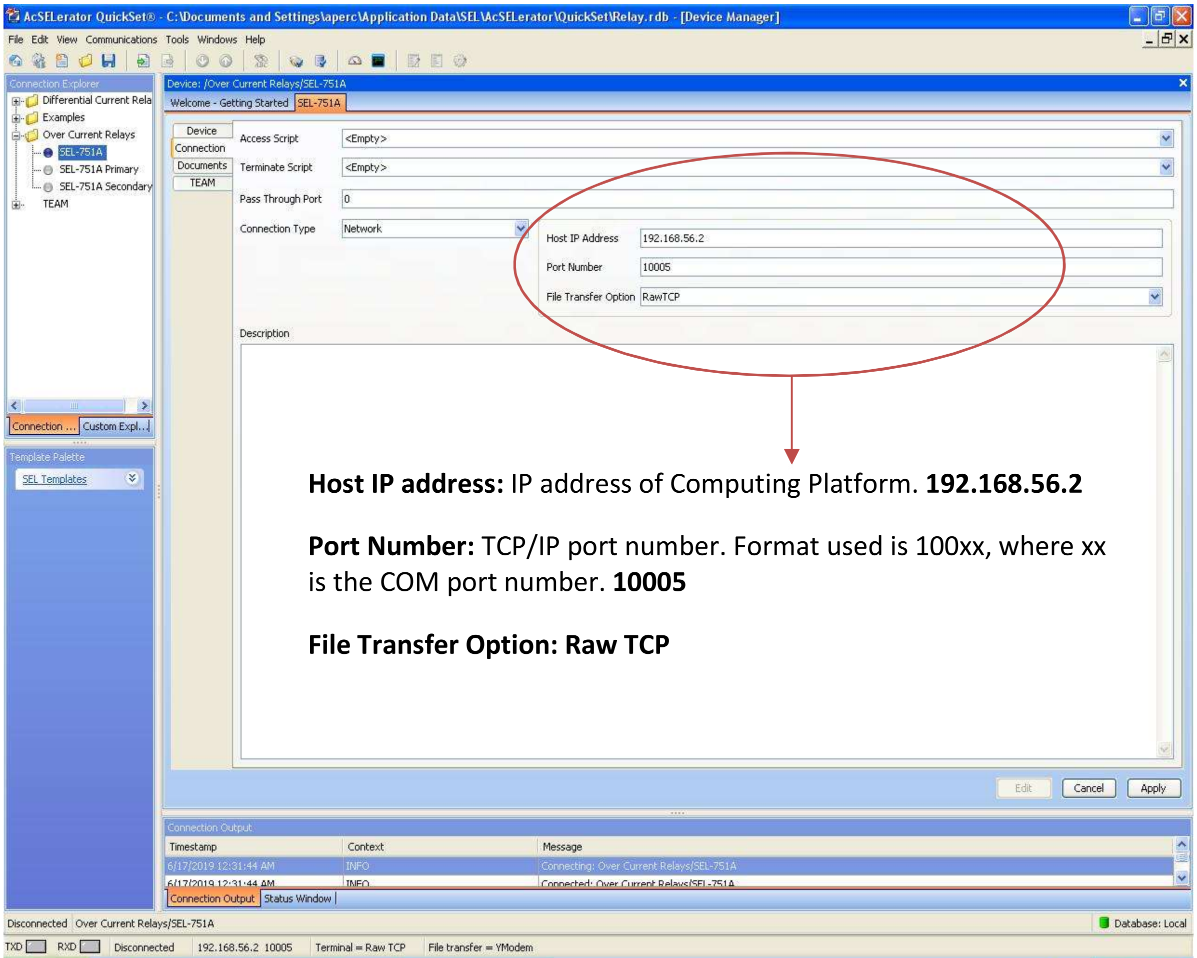


Figure 4.31 Entering communication parameters.

5) Once the communication parameters for the device are set, then the connection with device is made by right clicking on the device name under folder name on the left-pane. The first option on the window that appears 'Connect' is then selected. This is shown in Figure 4.32.

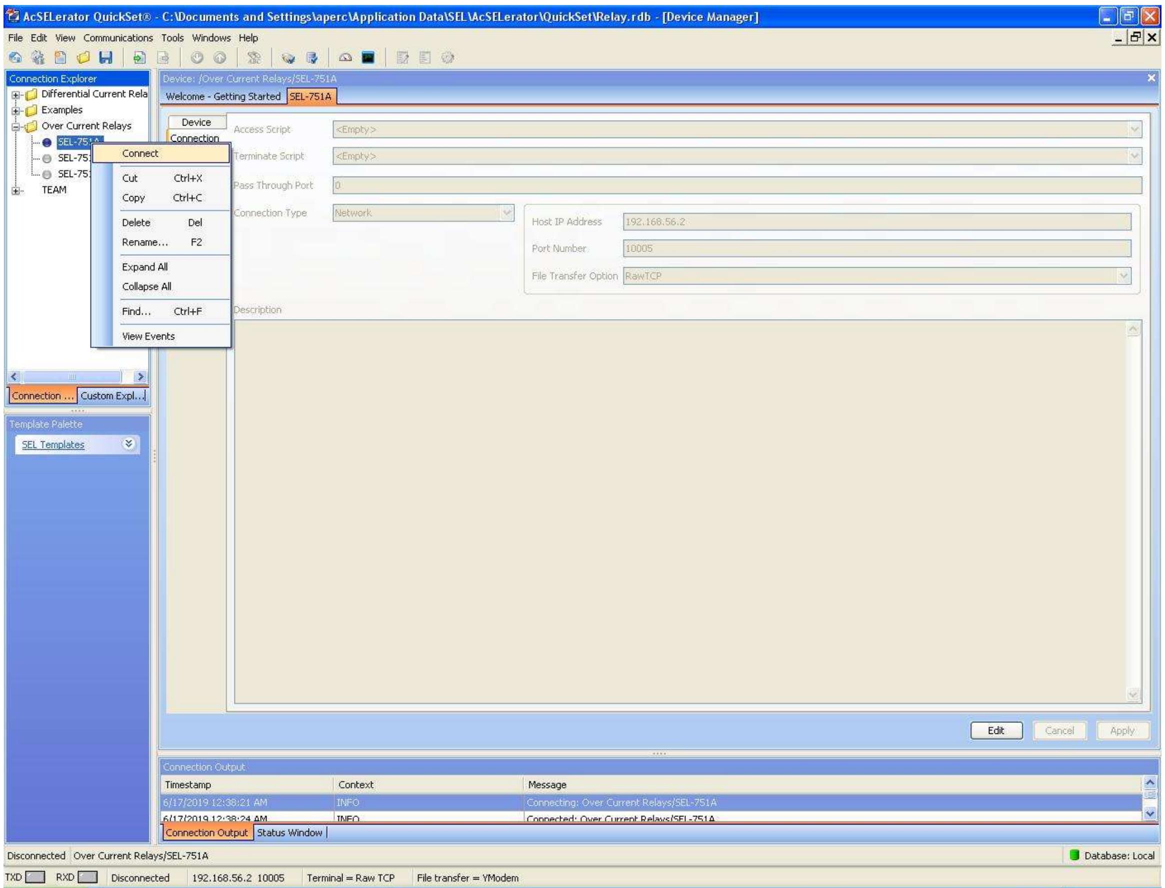


Figure 4.32 Connecting a relay with QuickSet

6) Once connection parameters of a device are defined, it becomes easier to connect the device. Save any changes if prompted to do so. To connect to a defined device requires only to right click on the device name and select 'Connect' as described in the previous step. A connected device can be disconnected in the same way. When a device is connected, the device name will have a green dot. Right clicking on the device name will give the option of 'Disconnect'. A disconnected device will have a grey dot followed by the device name. When the device name is selected the dot turns blue.

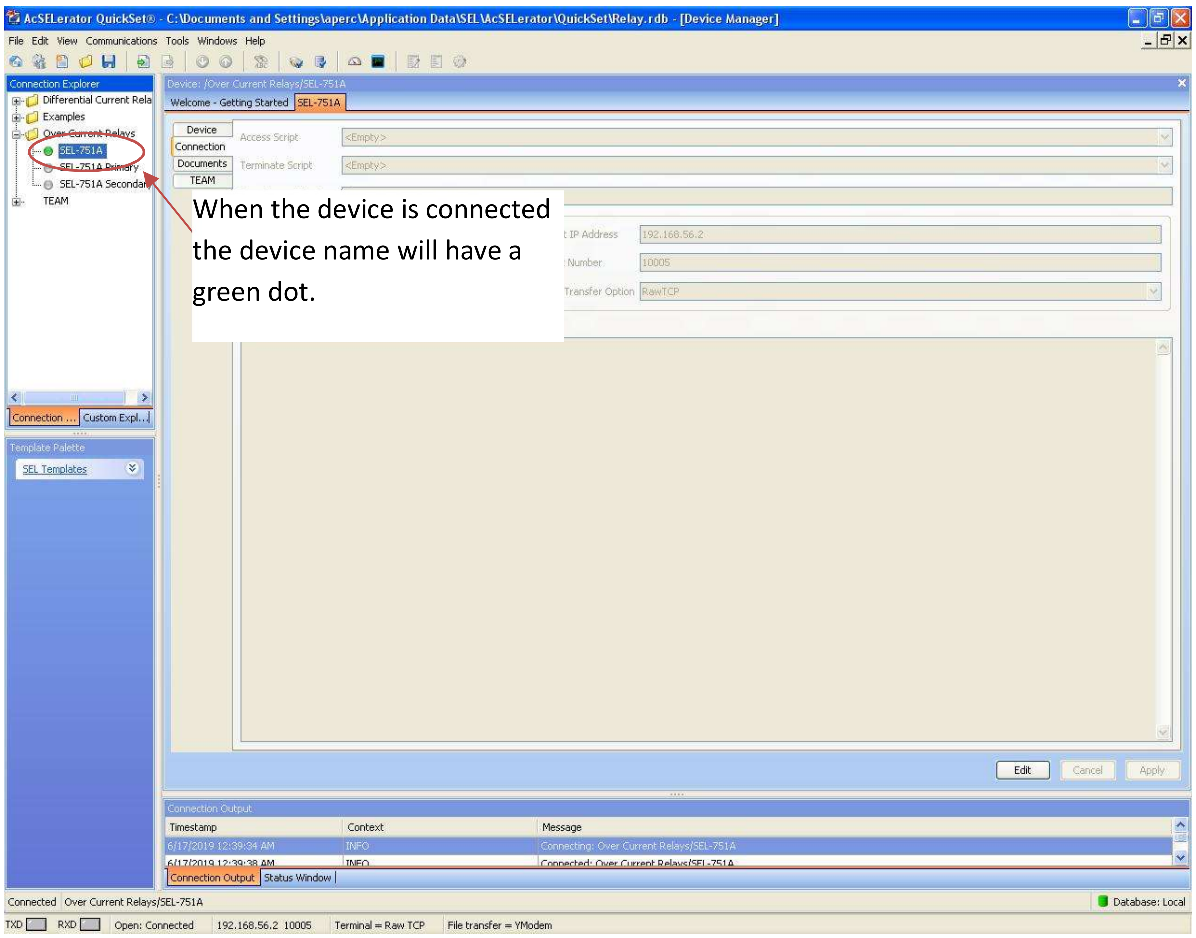


Figure 4.33 Connected device

4.5. SEL 751-A Feeder Protection Relay Settings

SEL-751A device settings can be read and modified either by accessing a device with QuickSet, or by accessing the settings directly using a terminal emulator. QuickSet has a "Terminal" option available which can be used for this purpose.

The following describes how device settings can be accessed and modified with the above-mentioned options.

4.5.1. Accessing and Modifying SEL Relays Settings with QuickSet

AcSELerator QuickSet provides option of reading data of a relay that is connected. Once the data from a device is obtained, it can be modified and sent to the device. This is described as follows,

1) Connect a relay with QuickSet as described in 4.4.1 or 4.4.2.
2) Click on the "Read Settings From Device" option from the main menu as shown in Figure 4.5.1.1.

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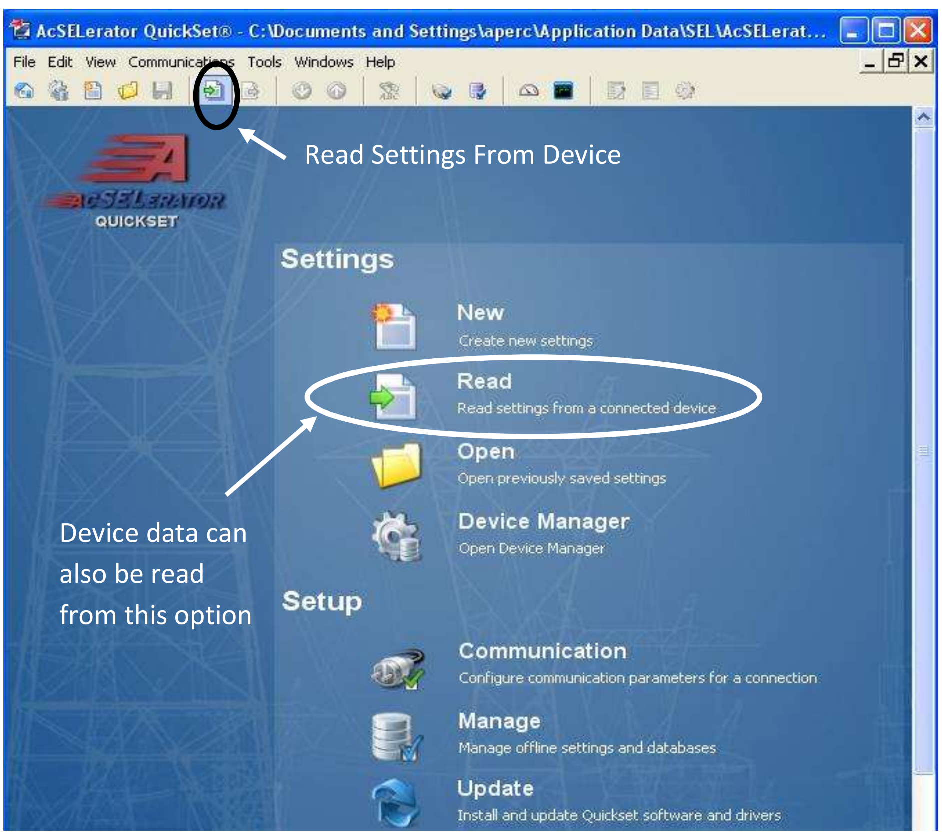


Figure 4.34 Reading data from a connected device

3) If the device is connected through the database as described in section 4.4.2, then device data can also be read as shown in Figure 4.35.

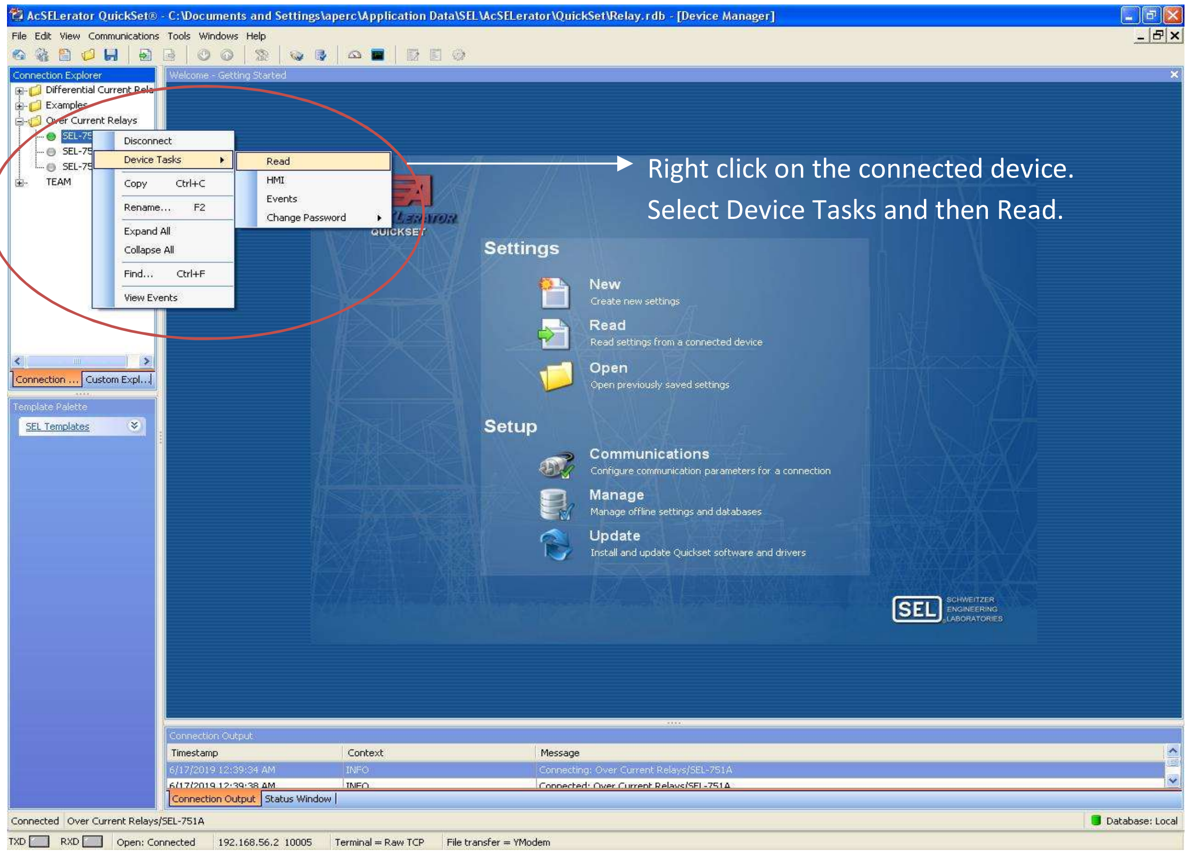


Figure 4.35 Reading device data of a relay configured in database.

A window as shown in Figure 4.36 will appear indicating that device data is being read.

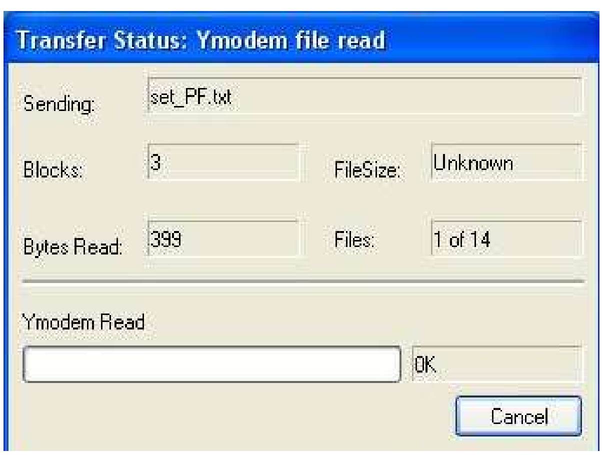


Figure 4.36 Device data being read from relay

4) When the reading process is complete, user can access the settings of the device. Clicking on a particular setting will open details for each setting option. New values can be entered as shown in Figure 4.37. Relay protection settings are under Group1 → Set1. Logic settings are under Group 1. Once new settings have been entered, the new values can be sent to the relay by clicking on the "Send Active Settings" option on the main menu.

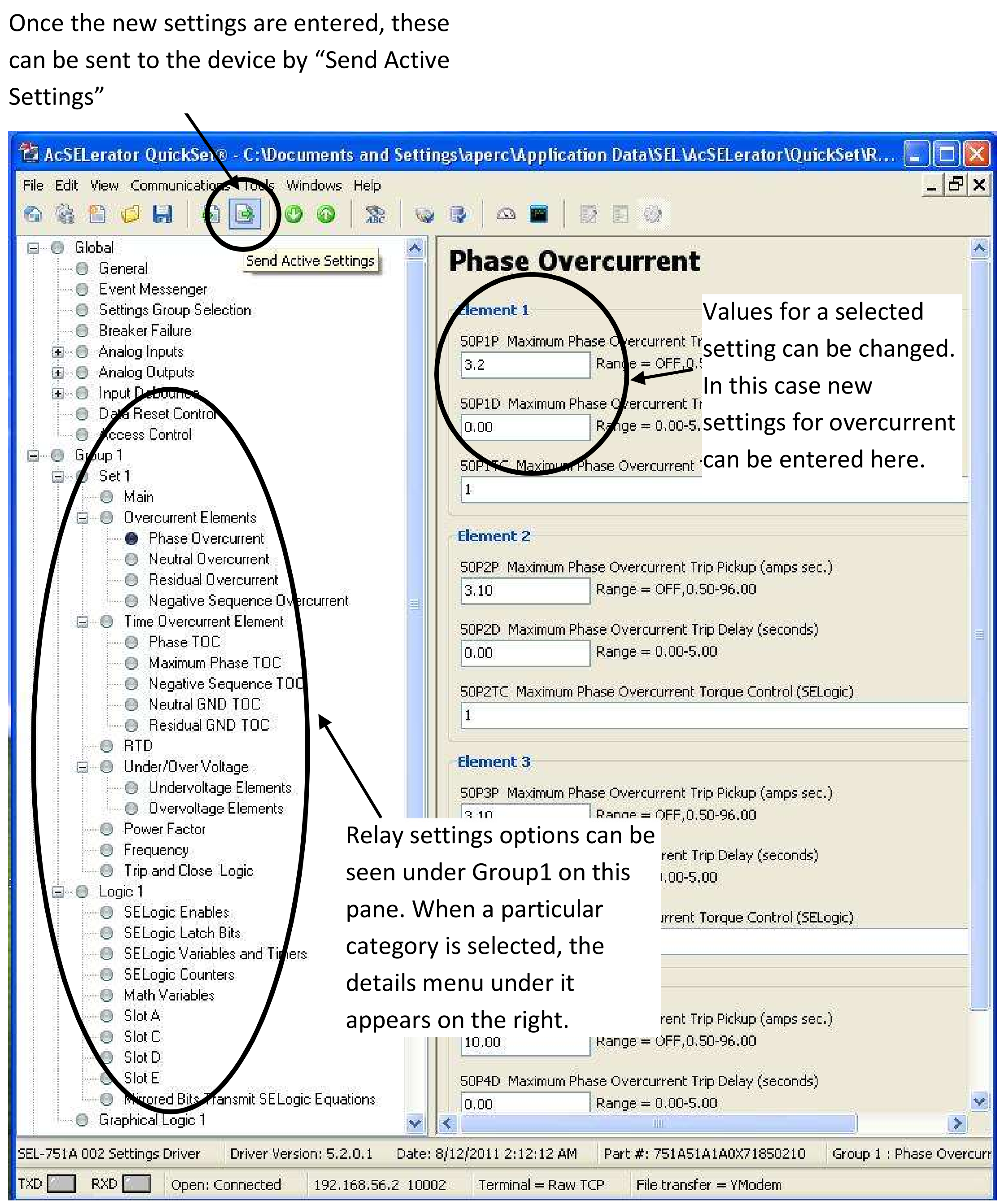


Figure 4.37 Detailed device settings. Settings can be read, modified and sent to device.

5) The software asks the user which settings have to be sent. If any changes in the protection are made, then only “Set 1” has to be sent. If any changes in the logic settings are made under “Logic 1” then only “Logic 1” can be sent. The software offers an option of saving new settings. Saving settings can be convenient as the same settings can be used later on without the need of reading the relay data.

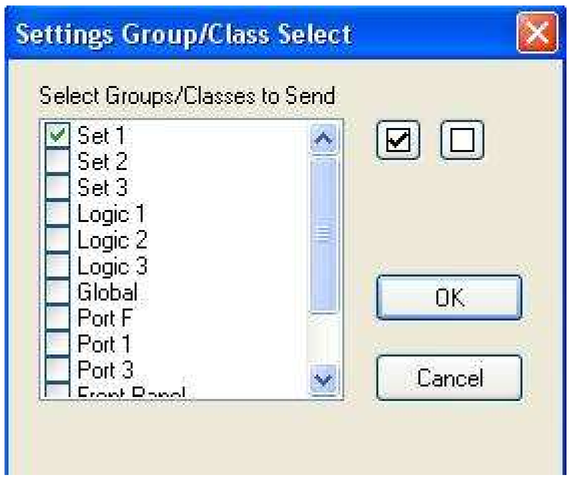


Figure 4.38 Selecting settings to send to the device

Figure 4.39 Relay data can be saved in PC and loaded and sent to relay latter on.

4.5.2. Accessing and Modifying SEL Relays Through Terminal

SEL relays' settings can also be accessed and modified through a terminal emulator and ASCII commands. Terminal is available in ACSELERATOR QuickSet® 5030 software. When a device (SEL-751-A) is connected with ACSELERATOR QuickSet® 5030 software, then Terminal can be launched from its icon on the main menu. This is shown in figure 4.40.

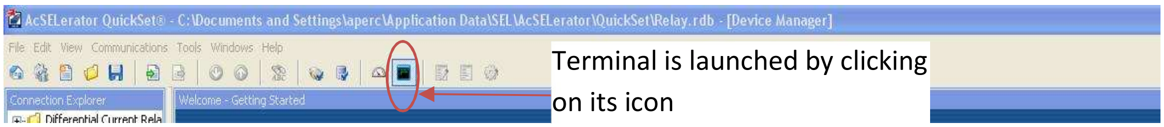


Figure 4.40 Launching Terminal from ACSELERATOR QuickSet

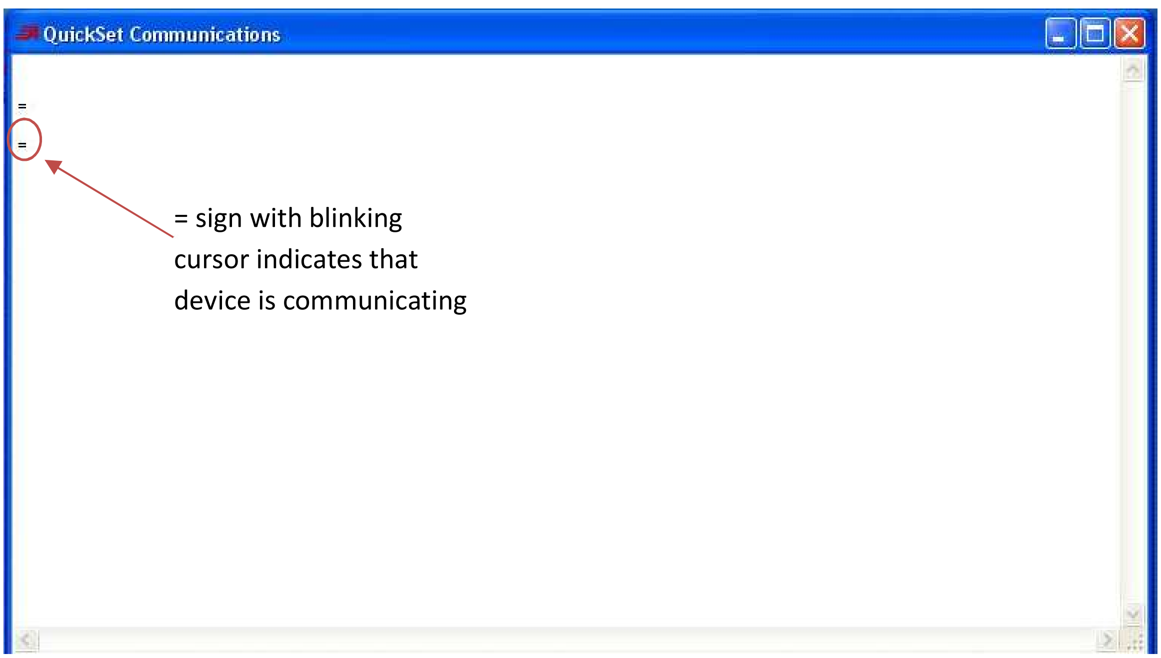


Figure 4.41 Terminal window

When the relay is communicating, user can enter commands to access and modify relay settings. Although, there are three levels to access SEL -751A relay as described in section 7 of SEL [2], however the two useful levels are 'level 1' and 'level 2'. At level 1, user can view the settings only and not modify any settings. For modifying (changing value) a setting, user must be at level 2. Table 4.5 describes the two levels.

Table 4.5 SEL-751A levels details

Level	Access Command	System Prompt	Level Default Password
1	ACC	=>	OTTER
2	2AC	=>>	TAIL

When the Terminal is launched, the first thing to do is to access level 1 of relay settings. This is done by typing ACC after the = sign. The system will prompt the user to enter the password for level 1. When the password is entered the = sign prompt will change to =>, indicating that the user is now at level 1. At this level relay settings can be viewed by typing SHO or SHOW command. This is shown in Figure 4.42. The relay settings under various categories, pertinent to this project, are listed in Table 4.6. Complete settings details are available in SEL [2] Section 6 “Settings”.

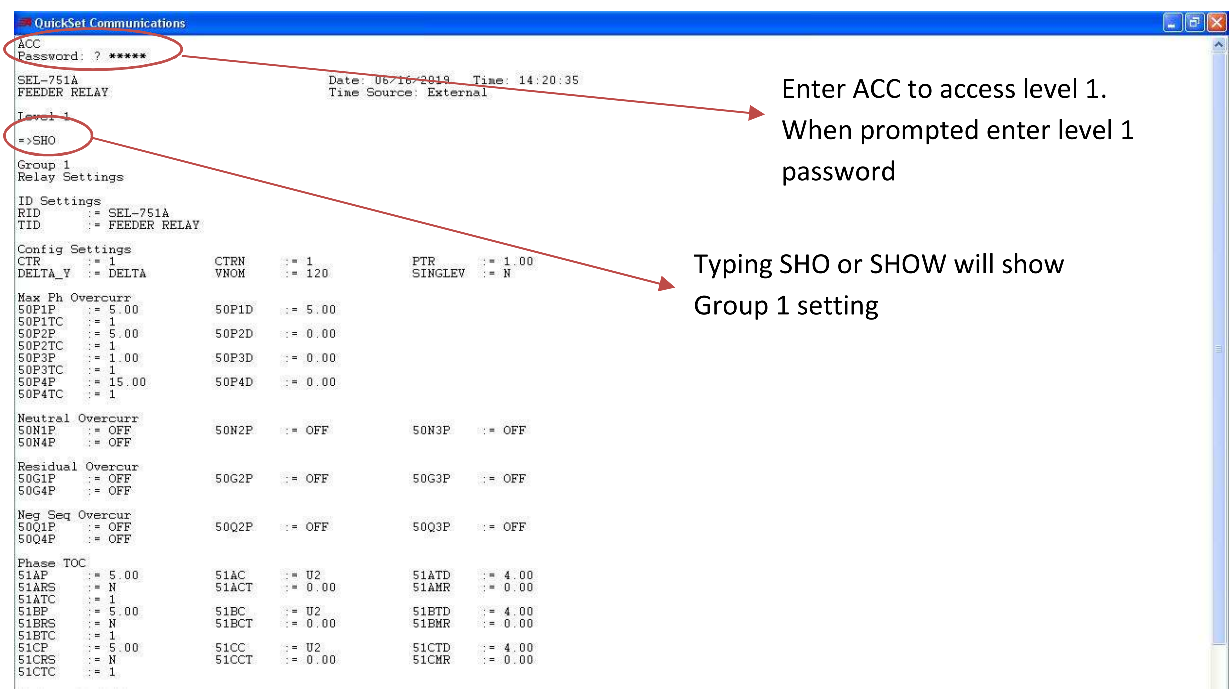


Figure 4.42 Level 1 of SEL-751A. SHO is entered to show relay settings

Table 4.6 SEL-751A Settings categories pertinent to this project.

Setting Category	Description	View Settings SEL Command	Modifying Setting SEL Command
Date	Show/modify the date configured in the device	SHO D	SET D
Front Panel Settings	Show/modify device's front panel settings	SHO F	SET F
Global Settings	Show/modify Global settings	SHO G	SET G
Relay Settings	Show/modify settings under GROUP. This category lists the protection settings of the relay.	SHO	SET
Logic Settings	Show/modify settings under LOGIC. This category is important as it lists the relay output assignments.	SHO L	SET L
Port	Show/modify the settings of relay ports	SHO P x, Where 'x' is the port on the relay. x= 1, 3 or F	SET P x Where 'x' is the port on the relay. x= 1, 3 or F
Report Settings	Show/modify Report settings	SHO R	SET R
Time	Show/modify the relay time settings	SHO T	SET T

The settings under each category can be viewed in level 1 or level 2 by typing SEL command for the required setting, listed in Table 4.6. For example, to view the Logic settings, SHO L is typed. Similarly, typing SHO will show protection settings of the relay.

In order to modify a setting, a user needs to be in level 2. This can be done by typing 2AC when user is at level 1. The system will prompt the user for level 2 password. Level 2 is indicated by prompt =>>. At this level, user can change a setting under a category by typing the commands listed in Table 4.6 For instance, relay protection settings can be modified by issuing the SET command in level 2. The device will move through each setting under the category by showing the present value of the setting followed by a '?'. The user has the option to enter a new value for the setting after '?' and press the "Enter" key to move onto the next setting option. If no modification is required then "Enter" key should be pressed after the '?'. The device will move onto to the next setting option. Once all the settings have completed and if modifications have been made in the settings, the device will ask whether to save the changes or not. Pressing ‘Y’ will save the changes and pressing ‘N’ will ignore the changes and keep original settings.

The relay settings, which are shown by SHO command and can be modified by SET command, include configuration settings, various protections settings and trip logic equations which are used to issue alarm and change the output contacts of the relay to operate connected breakers. Configuration settings include CT ratio, PT ratio, nominal line to line voltage and transformer connection settings. The relay offers instantaneous and time- phase, neutral, negative sequence and residual overcurrent protection; over and undervoltage protection; power factor (pf) lead lag protection; and frequency variation protection. The protection features can be configured with different trip levels making the relay versatile in application. These settings also include trip variables and word bits which can be modified for a customized operation of relay. Important of these are,

1) **TR**-which assigns a word bit TR to a logical equation that incorporates the protection features of the relay. The logical equation uses AND, OR and NOT combinational logic elements to combine various protection elements. The default TR equation is given by,

TR: = ORED50T OR ORED51T OR 81D1T OR 81D2T OR 81D3T OR 81D4T OR 59P1T OR 59P2T OR 55T OR REMTRIP OR SV01 OR OC OR SV04T

Where,
ORED50T= OR output of all instantaneous current protection elements (50)
ORED51T= OR output of all time current protection elements (51)
81D1T= Frequency trip level 1 (81)
81D2T= Frequency trip level 2 (81)
81D3T= Frequency trip level 3 (81)
81D4T= Frequency trip level 4 (81)
59P1T= Level 1 phase overvoltage trip (59)
59P2T= Level 2 phase overvoltage trip (59)
55T= Power factor trip (55)
REMTRIP= Remote Trip

SV01= SEL logic variable 1

OC= Breaker open status

SV04T= SEL logic variable 4 timer output

2) **ULTRIP-** which assigns a variable ULTRIP to a logical equation that incorporates unlatching feature.
3) **REMTRIP-** this variable takes into account remote trip options. This is done by assigning SEL logical equation to REMTRIP variable. It usually involves assigning an input contact to REMTRIP.

Logic settings include logic enables, latch bit equations, SEL logic variables and more importantly output contact assignments and can be viewed by SHO L command and modified with SET L command. The relays' output contacts, which can be used to annunciate alarm devices or trip breakers, are assigned under Logic settings. TRIP word bit is associated with trip logic TR (described in the previous section). Trip settings in TR can be assigned to a contact by assigning the word TRIP to a contact. By default, TRIP is assigned to OUT103 output contact coil.

One disadvantage with using Terminal for viewing and modifying relay settings is that complete description of settings is not given and only SEL names of the settings are shown. For a complete definition of the setting options, section 4 and SEL-751A settings sheets in SEL [2] can be used. Appendix B lists the definitions of relay settings available in the relays installed in the test bench.

4.6. Monitoring

The relay readings can be monitored with Human Machine Interface (HMI) in QuickSet. This can be done with the following steps.

1) Connect relay with QuickSet as described in 4.4.1 or 4.4.2.

2) Click on the HMI icon on the main menu.

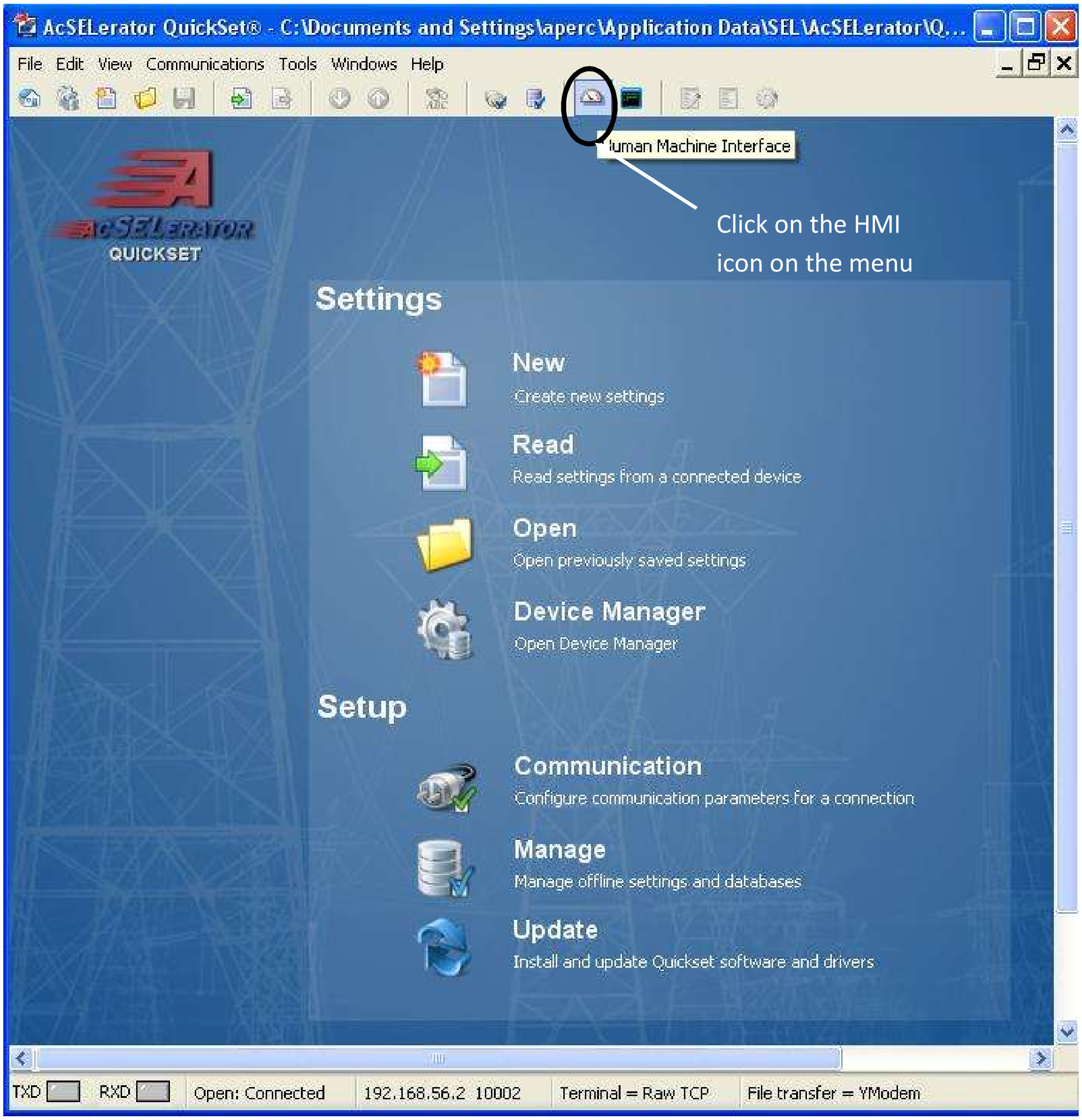


Figure 4.43 Accessing the HMI in QuickSet

3) The software reads the relay data. Once the data is read, the screen shown in Figure 4.44 will appear.

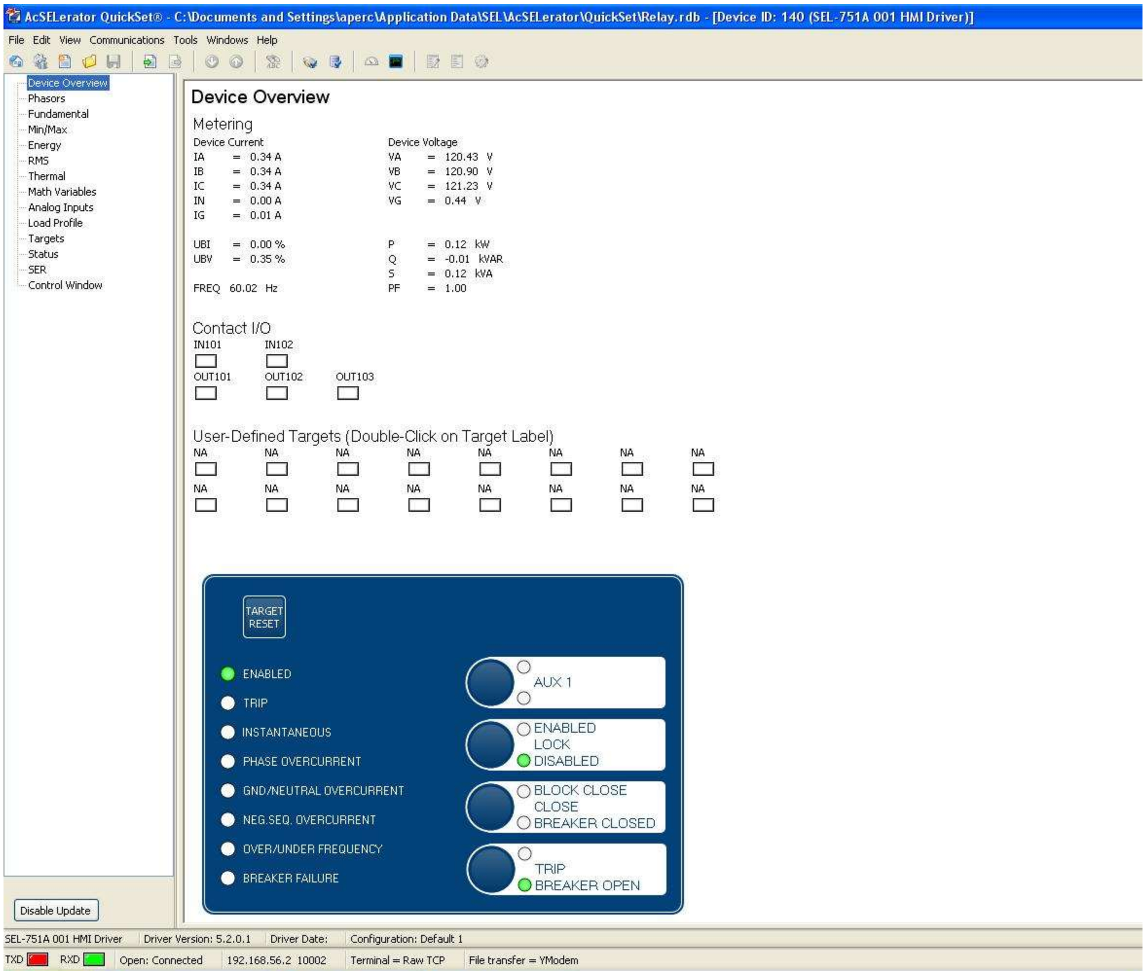


Figure 4.44 Device Overview on HMI

4) Phasor representation of live currents and voltages can be viewed by clicking "Phasor" option on the left menu. The buttons on the right of the plot can be clicked to show phasor representation of the current and voltage quantities. Clicking a button will press it and the phasor representation of the quantity will appear on the plot. Clicking a pressed button will release it and the phasor representation will be removed.

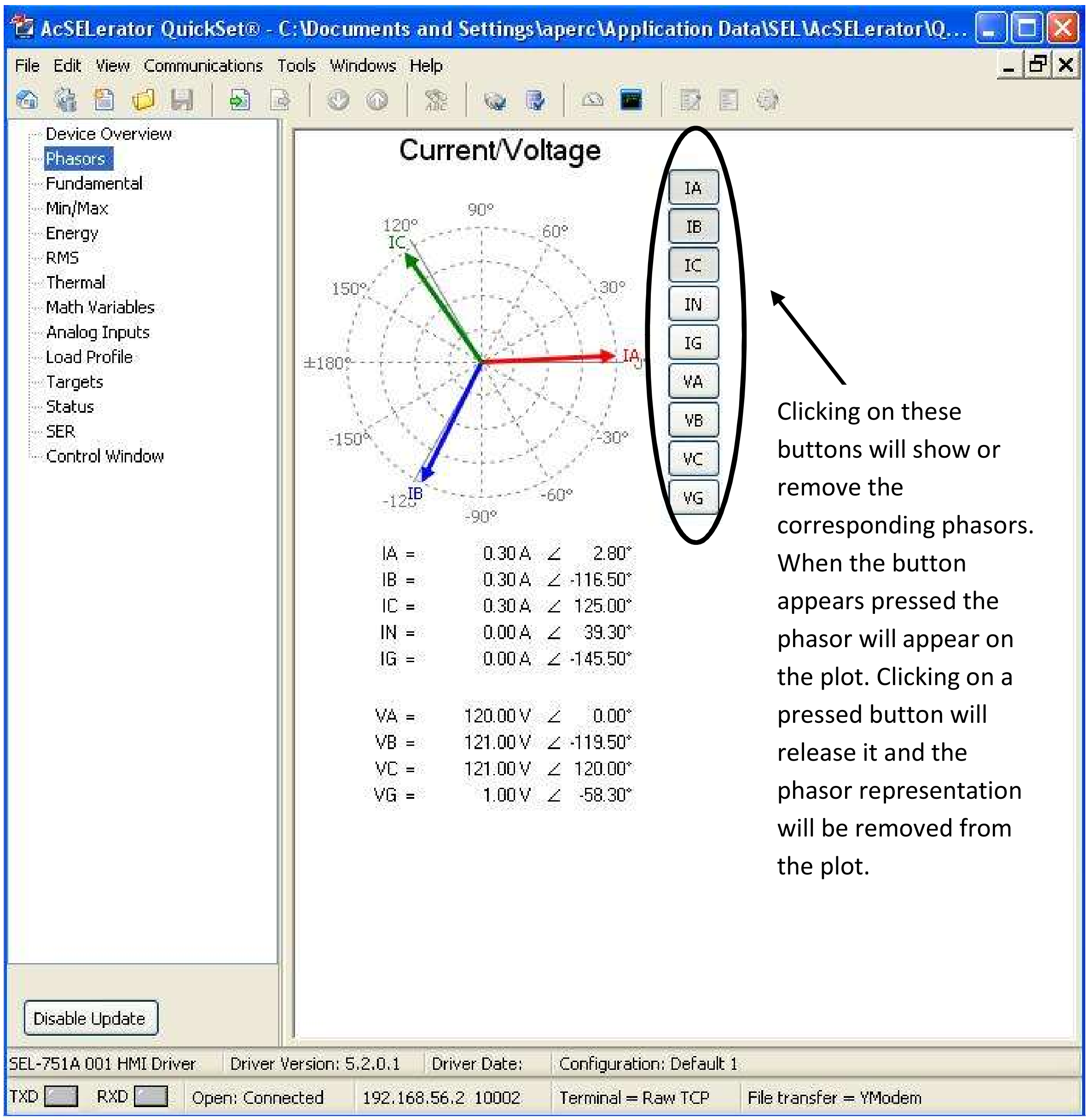


Figure 4.45 Viewing phasor representation of live current and voltage values.

In the phasor plot,

IA= Current of phase A

IB= Current of phase B

IC= Current of phase C

IN= Current through neutral. As neutral is not connected through the relay, this should be zero.

IG= Phasor sum of IA, IB and IC

VA= Phase voltage of phase A

VB= Phase voltage of phase B

VC= Phase voltage of phase C

VG= Phasor sum of VA, VB and VC

5) Fundamental metering values can be viewed by clicking on "Fundamental" option on the right pane.

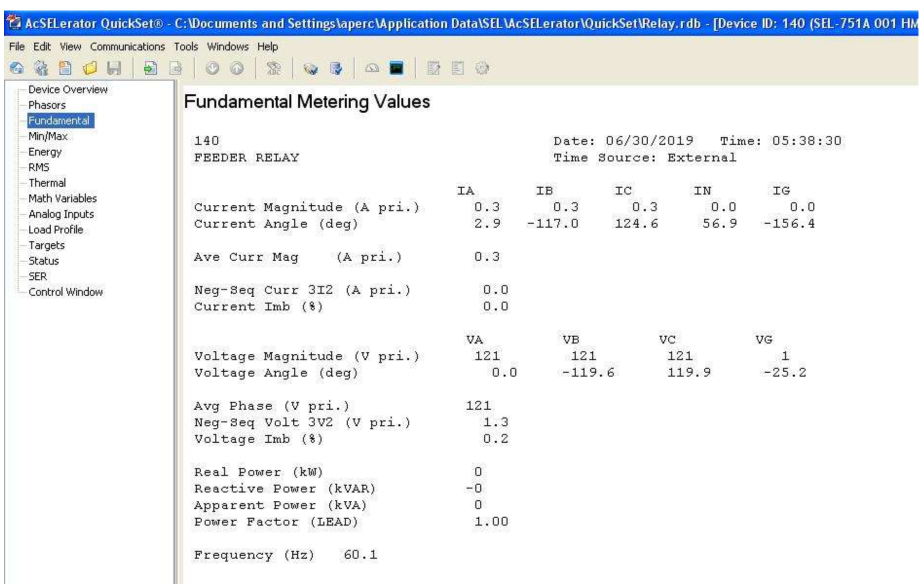


Figure 4.46 Fundamental metering values

6) Events can be saved and viewed by going to Tools → Events → Get Events Files, as shown in Figure 4.47.

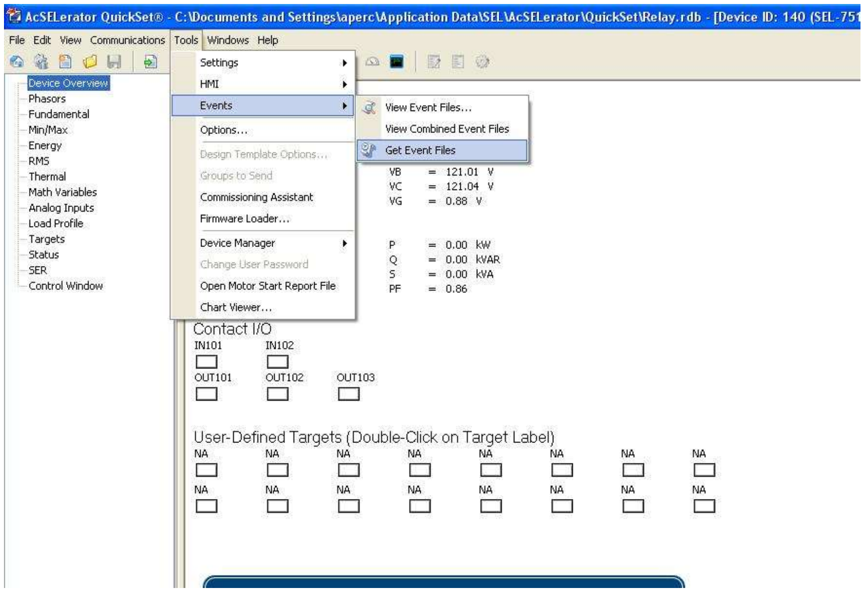


Figure 4.47 Getting Events Files

7) The software shows a list of events. Event of interest can be selected. After this "Get Selected Events" button is clicked.

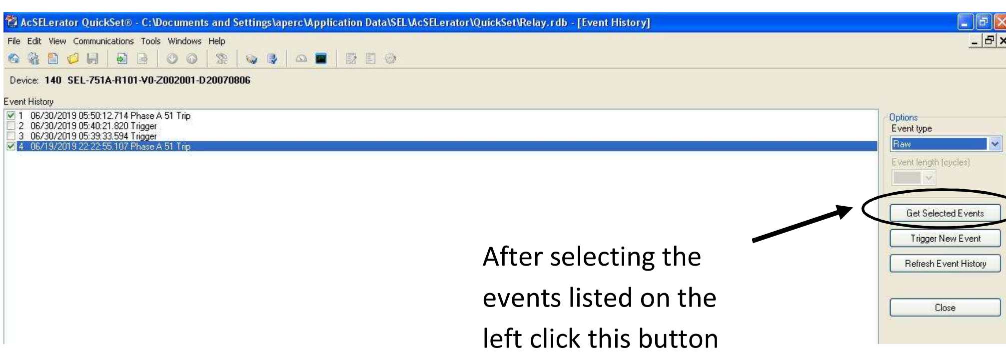


Figure 4.48 List of events.

8) Once the software gets the event data, a window to save the Events will open. Select the folder to event file.

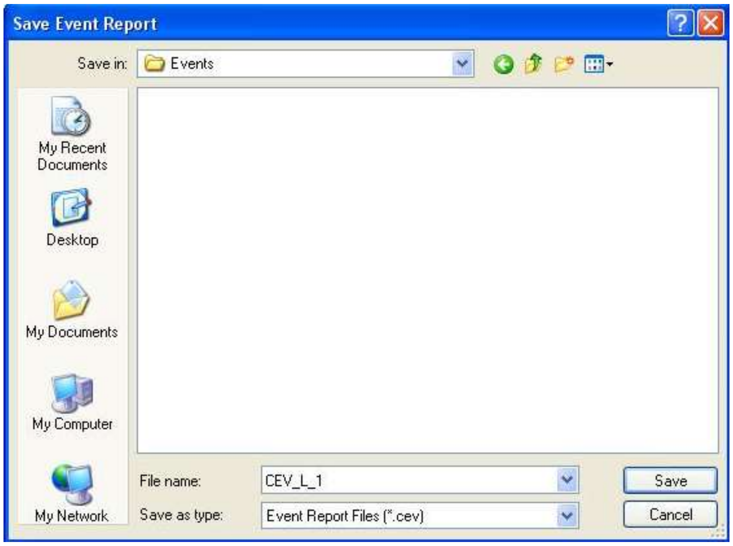


Figure 4.49 Saving Events

9) From start menu select All Programs → SEL Applications →AcSELerator Analytic Assistant.

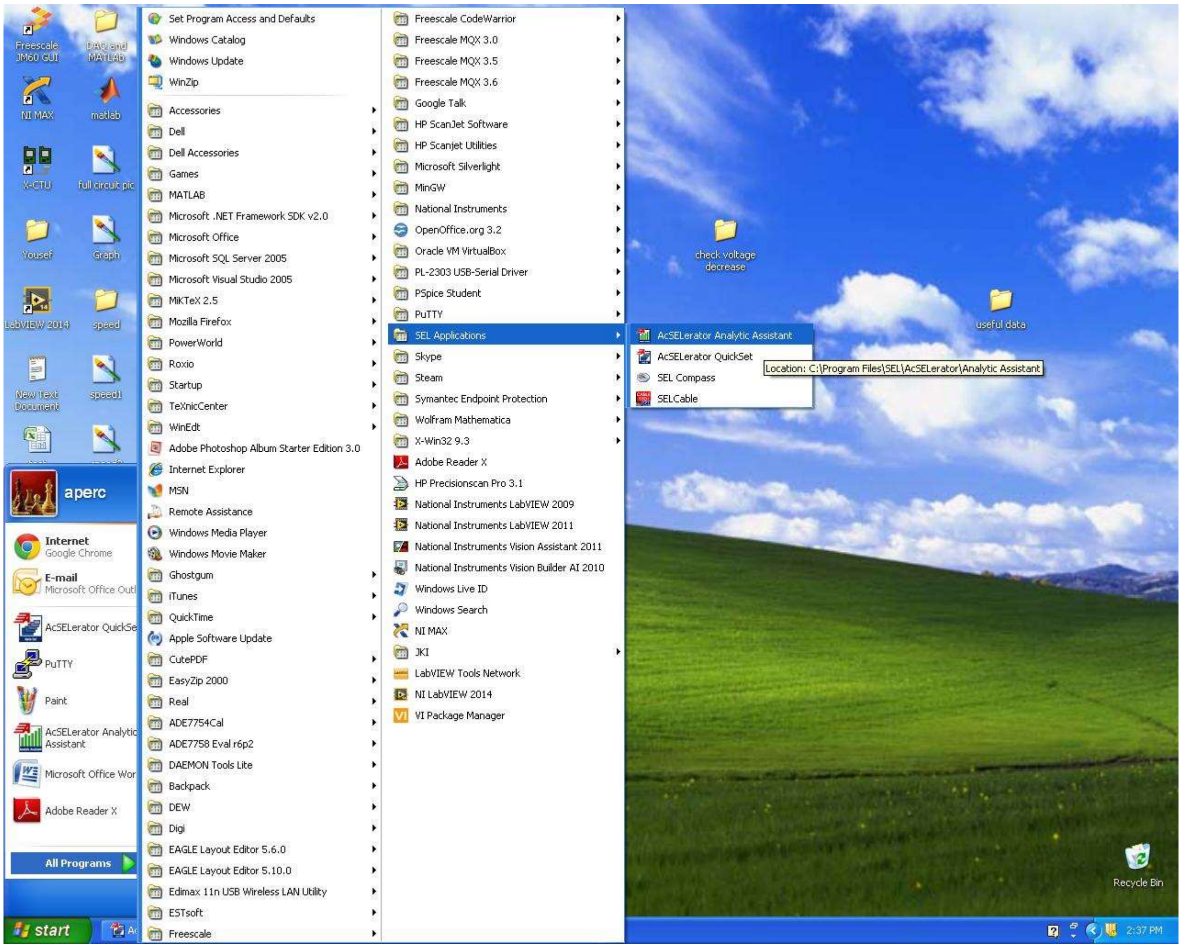


Figure 4.50 Opening AcSELerator Analytic Assistant in the lab PC

10) From the file menu select the location of the event file.

Figure 4.51 Opening event file in in AcSELerator Analytic Assistant

The event file will show the waveforms of currents and voltage. User can also see the phasor representation of the voltages and currents.

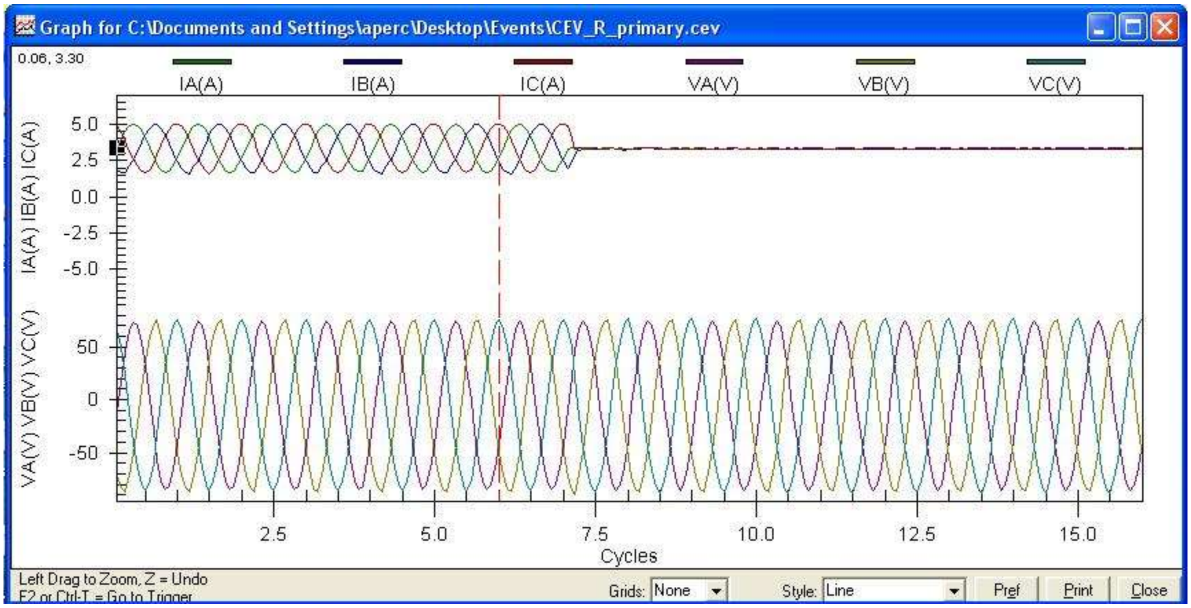


Figure 4.52 Graphs of currents and voltages from the event file. Phasor representation can also be obtained from the options.

Metering data can also be viewed from the Terminal by issuing MET command in level 1 or level 2. However, the metering values are not updated (live readings) and each time new readings are required, MET command has to be issued.

CHAPTER 5

FUTURE WORK

Based on the success of this project, it is planned to build a similar bench for demonstrating differential current protection. For this purpose, a SEL-387A Current Differential Relay can be used. Tripping can be achieved with a similar breaker circuit that has been designed and implemented in this project. The proposed schematic for the Differential Current Protection Relay Test Bench is given in appendix A3. This circuit was tested with both line to line and line to neutral faults. The relay was able to detect the imbalance in the currents between the primary and secondary sides of a variable autotransformer. As a part of this project, the SEL-387A Current Differential Relay has already been configured with ACSELERATOR QuickSet®.

The proposed design is similar to example given in SEL [6] (figure 2.7 pp 2.10) and uses SEL-387A relay with a variable autotransformer. The difference in the proposed design is that it will employ only one breaker circuit, which has been designed in this project, on the primary side of the transformer. Load connection points for introducing a line to line and a line to neutral fault will be included on the primary side. The proposed design also will not have its neutral connected with SEL-387A relay.

As per the suggested design the current differential has its primary (IAW1, IBW1 and ICW1) and secondary (IAW2, IBW2 and ICW2) pick up elements connected across the transformer. Three phase loads can be connected through load connection port. Fault creating loads are connected on the primary side of the autotransformer after IAW1, IBW1 and ICW1. When a fault is introduced, it will create an imbalance between the current flowing through the primary side and secondary pickup elements and the relay will close its contact OUT103 which will trip the breaker circuit and the connection between the incoming AC supply and primary side of the variable autotransformer will be broken.

The setup used to test the suggested circuit for the differential current protection is shown in Figure 5.1.

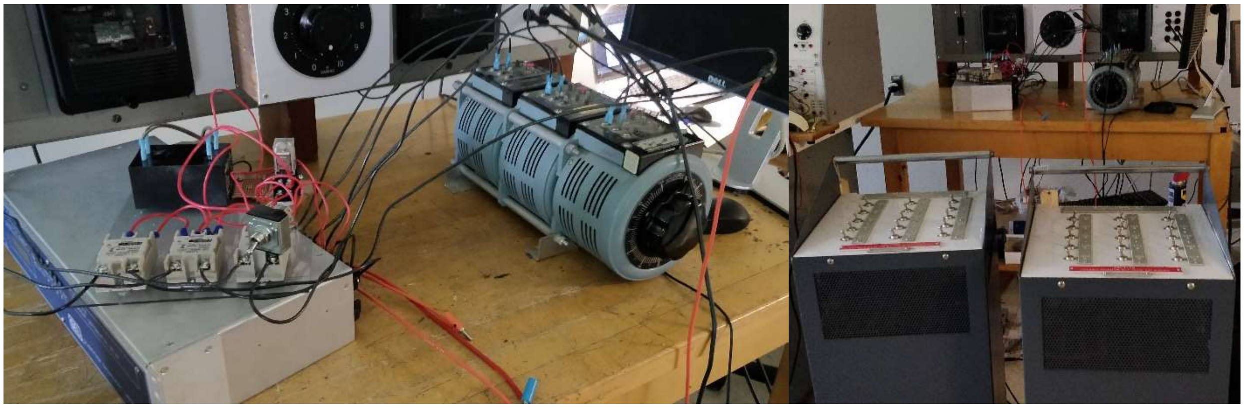


Figure 5.1 Differential current protection circuit test setup

Live readings from the current differential relay were observed using HMI in AcSELerator QuickSet®. The snap shot in Figure 5.2, 5.3 and 5.4 show device overview during normal operation, differential current phasors and device overview when a fault is detected by the relay and the relay initiates a trip, respectively.

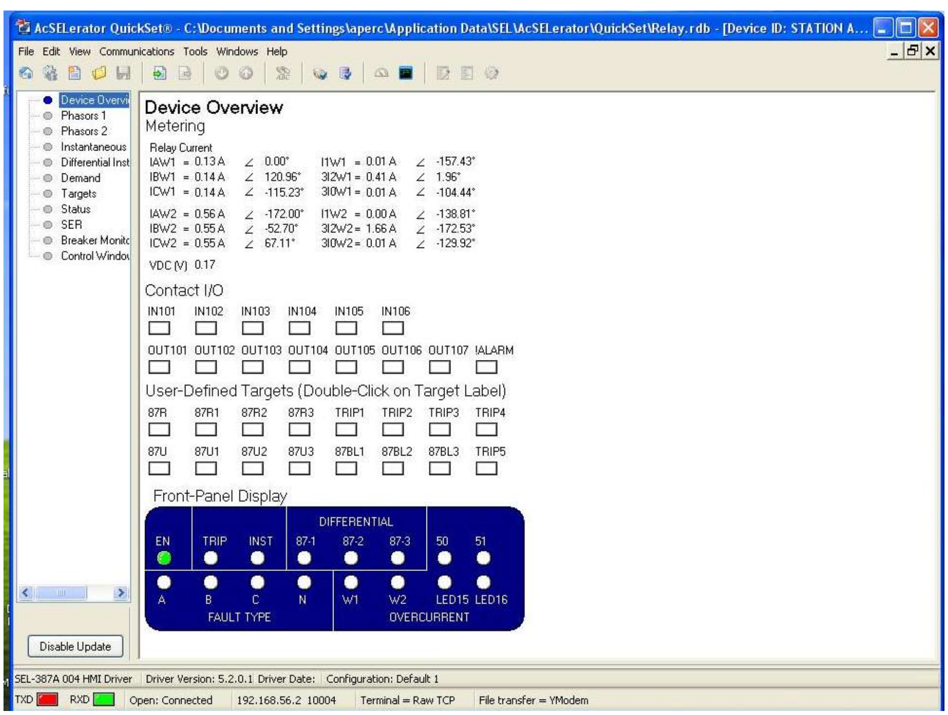


Figure 5.2 Device Overview of SEL-387A during normal operation.

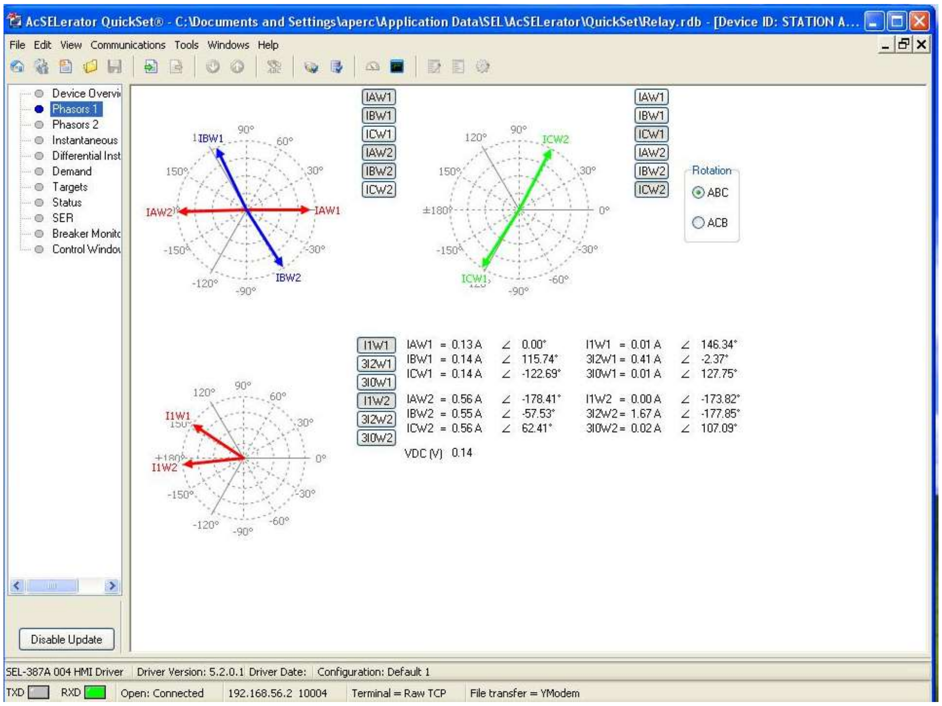


Figure 5.3 Phasor representation of differential currents.

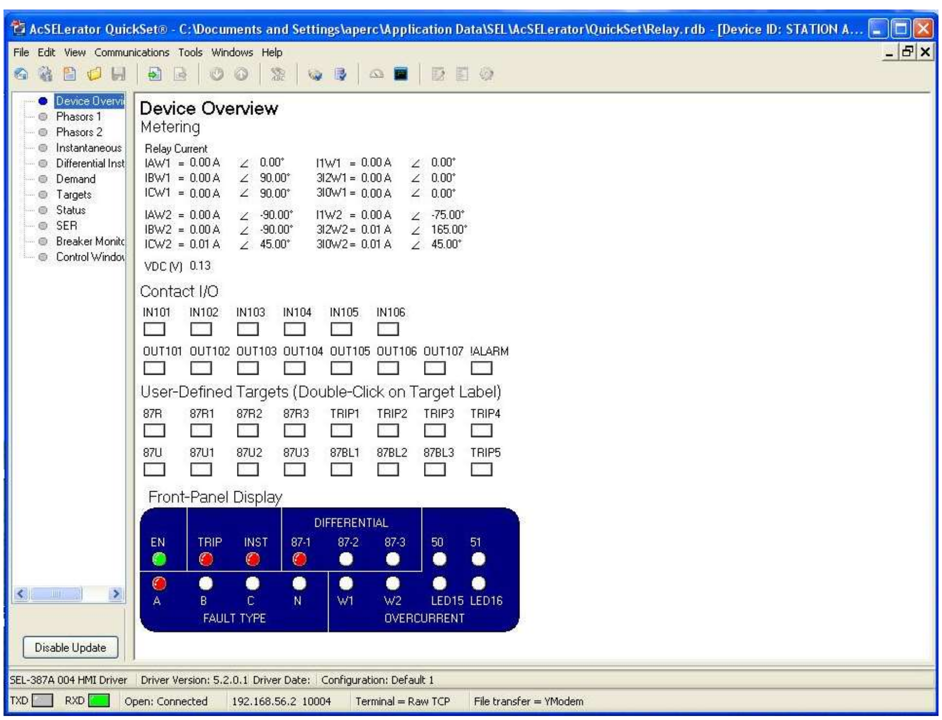


Figure 5.3 Device Overview of SEL-387A when relay trips.

Appendix

Appendix A- Overcurrent Protection Relays Test Bench Circuit Schematics

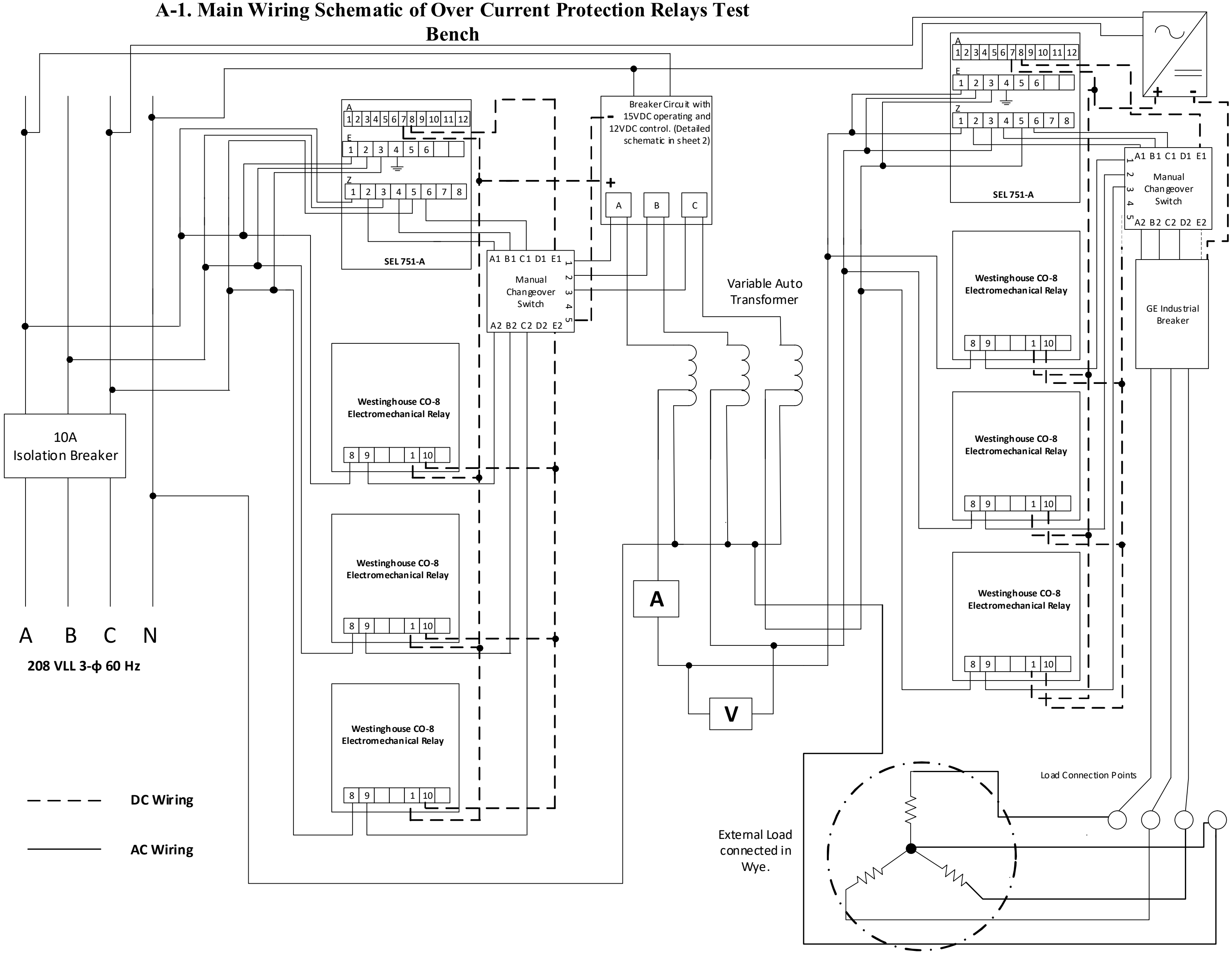
Appendix B- SEL -751A Settings Definitions

Appendix C- US Inverse Time Relay Operating Time vs. Multiples of Pick-up Current

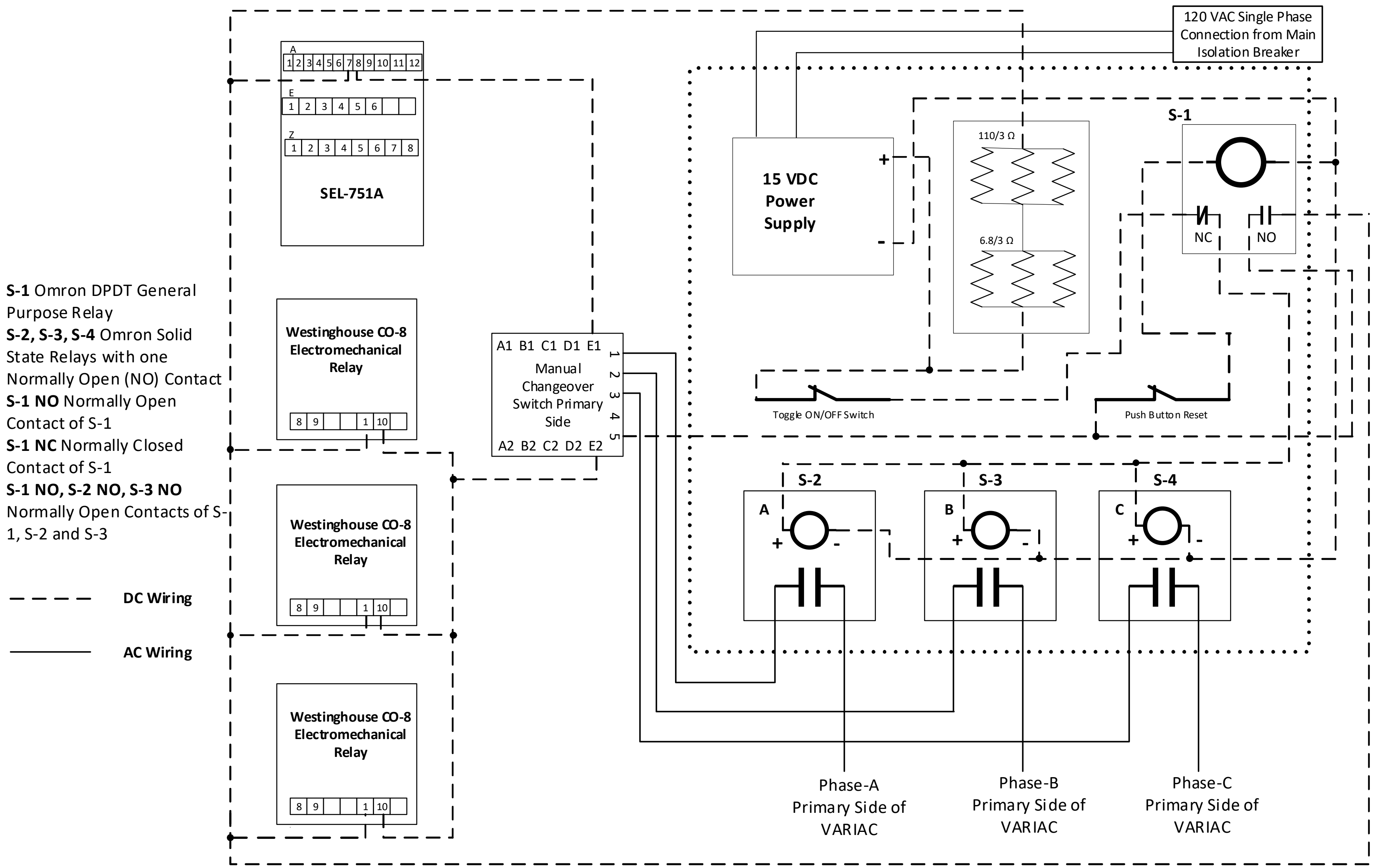
Appendix D- List of Passwords

Appendix E- Parts List

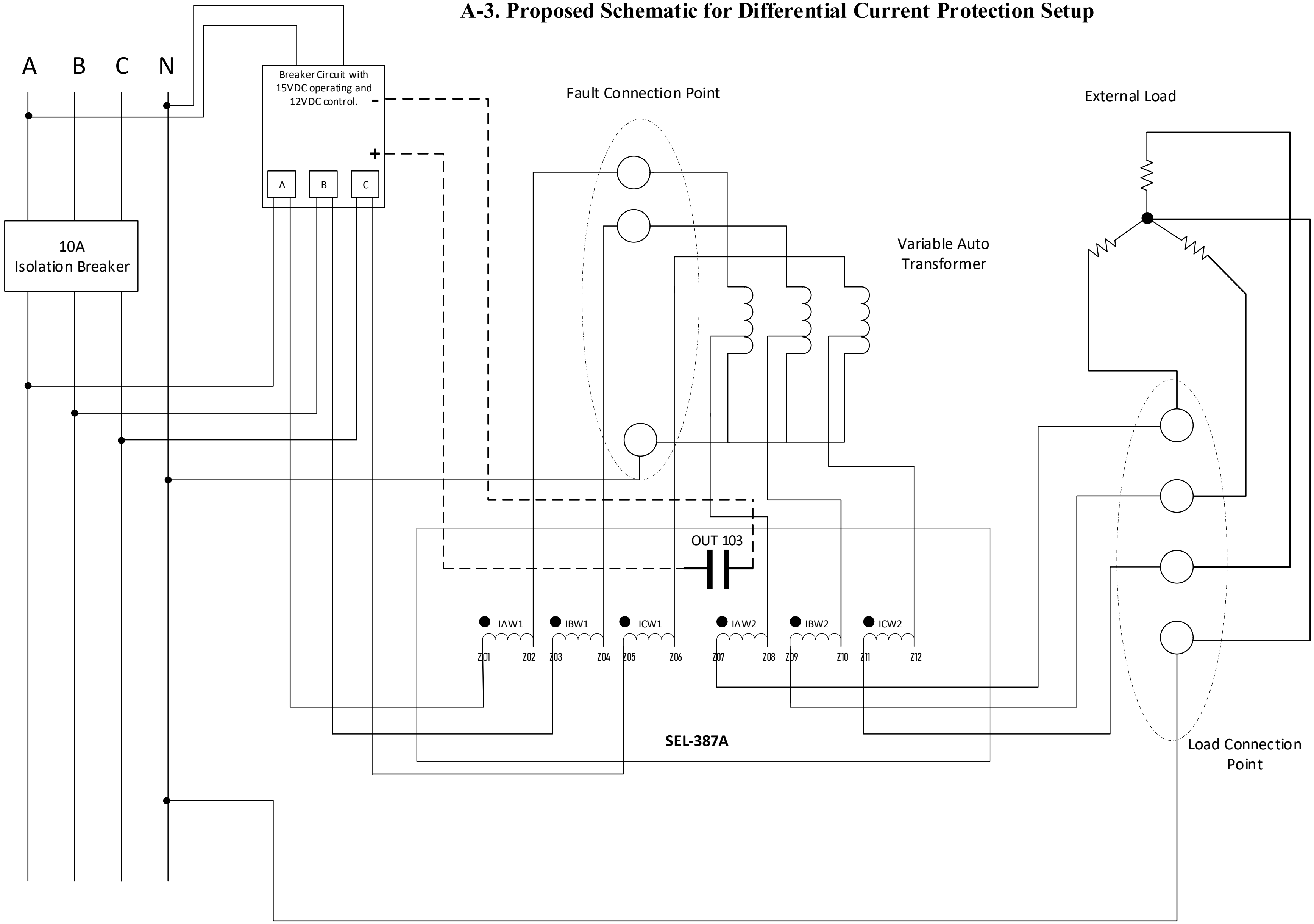
A-1. Main Wiring Schematic of Over Current Protection Relays Test Bench



A-2. Wiring Schematic of Beaker Circuit for Primary Side Protection



A-3. Proposed Schematic for Differential Current Protection Setup



B- SEL-751A Relay Settings Definitions Pertinent to This Project from SEL [2]

SEl-751A Relay Protection Settings SHO and SET			
Setting Category	**Setting SEL Name**	**Setting Definition**	**Setting Options**
ID	RID	Relay ID settings	SEL-751A
	TID	Relay ID settings	FEEDR RELAY
Configuration	CTR	Phase CT Ratio. Value between 1-5000 can be set. This should set to ‘1’ because in this project no CTs have been used	1-5000
	CTRN	Neutral CT Ratio. Value between 1-5000 can be set. This should set to ‘1’ because in this project no CTs have been used.	1-5000
	PTR	Phase PT Ratio. Value between 1.00-10000.00 can be set. This should be set to ‘1’ because the test bench does not use PTs.	1.00-10000.00
	DELTA_Y	Transformer Connection. This should be set at WYE.	WYE, DELTA
	VNOM	Line to Line Voltage. This is set at 208 V.	20-250 (DELTA_Y =DELTA) 20-440 (DELTA_Y =WYE)
	SINGLEV	Single V Input. This is set at N because we have three phase voltage.	Y, N
Instantaneous Protection Settings	50P1P	Maximum Phase Overcurrent Trip Level 1. Trip current level is in Amps. This should not exceed 3.5 A.	OFF, 0.50–100.00
	50P1D	Maximum Phase Overcurrent Trip Delay 1. Time in seconds.	0.00–5.00
	50P1TC	Maximum Phase Overcurrent Torque Control 1. When a SELogic expression is assigned to this bit then it will be true when the expression becomes true and only then 50P1P will be functional. For example, setting 50P1TC=IN101 will make 50P1TC true when IN101 (digital input) is true. If no logic expression is assigned then it should be assigned a value of 1 (true) so that 50P1P is functional.	Default value used, if no logical or external control is required, is 1
	50P2P	Maximum Phase Overcurrent Trip Level 2. Trip current level is in Amps. This should not exceed 3.5 A.	OFF, 0.50–100.00
	50P2D	Maximum Phase Overcurrent Trip Delay 2. Time in seconds.	0.00–5.00
	50P2TC	Maximum Phase Overcurrent Torque Control 2. Same applies to this setting as explained for 50P1TC.	Default value used, if no logical or external control is required, is 1
	50P3P	Maximum Phase Overcurrent Trip Level 3. Trip current level is in Amps. This should not exceed 3.5 A.	OFF, 0.50–100.00
	50P3D	Maximum Phase Overcurrent Trip Delay 3. Time in seconds.	0.00–5.00
	50P3TC	Maximum Phase Overcurrent Torque Control 3. Same applies to this setting as explained for 50P1TC.	Default value used, if no logical or external control is required, is 1
	50P4P	Maximum Phase Overcurrent Trip Level 4. Trip current level is in Amps. This should not exceed 3.5 A.	OFF, 0.50–100.00
	50P4D	Maximum Phase Overcurrent Trip Delay 4. Time in seconds.	0.00–5.00
	50P4TC	Maximum Phase Overcurrent Torque Control 4. Same applies to this setting as explained for 50P1TC.	Default value used, if no logical or external control is required, is 1

	50N1P	Neutral Overcurrent Level 1. We are not using neutral connection so it can be set at OFF.	OFF, 0.50–100.00
	50N2P	Neutral Overcurrent Level 2. We are not using neutral connection so it can be set at OFF.	OFF, 0.50–100.00
	50N3P	Neutral Overcurrent Level 3. We are not using neutral connection so it can be set at OFF.	OFF, 0.50–100.00
	50N4P	Neutral Overcurrent Level 4. We are not using neutral connection so it can be set at OFF.	OFF, 0.50–100.00
	50G1P	Residual Overcurrent Level 1. This should not exceed 3.5 A. The residual current IG is the phasor sum of phase currents IA, IB and IC.	OFF, 0.50–100.00
	50G2P	Residual Overcurrent Level 2. This should not exceed 3.5 A.	OFF, 0.50–100.00
	50G3P	Residual Overcurrent Level 3. This should not exceed 3.5 A.	OFF, 0.50–100.00
	50G4P	Residual Overcurrent Level 4. This should not exceed 3.5 A.	OFF, 0.50–100.00
	50Q1P	Negative Sequence Overcurrent Level 1. This should be set so that the maximum current does not exceed 3.5 A.	OFF, 0.50–100.00
	50Q2P	Negative Sequence Overcurrent Level 2. This should be set so that the maximum current does not exceed 3.5 A.	OFF, 0.50–100.00
	50Q3P	Negative Sequence Overcurrent Level 3. This should be set so that the maximum current does not exceed 3.5 A.	OFF, 0.50–100.00
	50Q4P	Negative Sequence Overcurrent Level 4. This should be set so that the maximum current does not exceed 3.5 A.	OFF, 0.50–100.00
Time Overcurrent Protection Settings	51AP	Phase A - Phase Current Trip Level. This should be set so that maximum current through a phase does not exceed 3.5A	OFF, 0.50-16
	51AC	Phase A - Phase Current Curve. The relay has options for various US and IEC curves, US: U1 (Moderately Inverse), U2 (Inverse), U3 (Very Inverse), U4 (Extremely Inverse), U5 (Short-time Inverse) IEC: C1 (Standard Inverse), C2 (Very Inverse), C3 (Extremely Inverse), C4 (Long-time Inverse), C5 (Short-time Inverse).	U1, U2, U3, U4, U5 C1, C2, C3, C4, C5
	51ATD	Phase A - Time Dial. 0.50-15.00 for US curves. 0.05-1.00 for IEC curves.	0.50 - 15.00 0.05 - 1.00
	51ARS	Phase A - EM Reset Delay. Setting this to 'Y' will introduce a reset delay which is a characteristic of electromechanical relays.	Y or N (default N)
	51ACT	Phase A - Constant Time Adder. Raises the curve by a constant time.	0.00-1.00
	51AMR	Phase A - Minimum Response Time of Curve	0.00-1.00
	51ATC	Phase A - Torque Control. When a SELogic expression is assigned to this bit then it will be true when the expression becomes true and only then 51AP will be functional. For example, setting 51ATC=IN101 will make 51ATC true when IN101 is true. If no logic expression is assigned then it should be assigned a value of 1 (true) so that 51AP is functional.	Default value used, if no logical or external control is required, is 1
	51BP	Phase B - Phase Current Trip Level. This should be set so that maximum current through a phase does not exceed 3.5A	OFF, 0.50-16
	51BC	Phase B - Phase Current Curve. The curve options are same as given for 51AC.	U1, U2, U3, U4, U5 C1, C2, C3, C4, C5
	51BTD	Phase B - Time Dial. 0.50-15.00 for US curves. 0.05-1.00 for IEC curves.	0.50 - 15.00 0.05 - 1.00
	51BRS	Phase B - EM Reset Delay.	Y or N

			(default N)
	51BCT	Phase B - Constant Time Adder. Raises the curve by a constant time.	0.00-1.00
	51BMR	Phase B - Minimum Response Time of Curve.	0.00-1.00
	51BTC	Phase B - Torque Control. Same applies to this setting as explained for 51ATC.	Default value used, if no logical or external control is required, is 1
	51CP	Phase C - Phase Current Trip Level. This should be set so that maximum current through a phase does not exceed 3.5A.	OFF, 0.50-16
	51CC	Phase C - Phase Current Curve. The curve options are same as given for 51AC.	U1, U2, U3, U4, U5 C1, C2, C3, C4, C5
	51CTD	Phase C - Time Dial. 0.50-15.00 for US curves. 0.05-1.00 for IEC curves.	0.50 - 15.00 0.05 - 1.00
	51CRS	Phase C - EM Reset Delay.	Y or N (default N)
	51CCT	Phase C - Constant Time Adder. Raises the curve by a constant time.	0.00-1.00
	51CMR	Phase C - Minimum Response Time of Curve.	0.00-1.00
	51CTC	Phase C - Torque Control. Same applies to this setting as explained for 51ATC.	Default value used, if no logical or external control is required, is 1
	51P1P	Maximum Phase Overcurrent 1 Trip Level. It is the maximum current through any phase A, B or C. This should be set so that maximum current through a phase does not exceed 3.5A.	OFF, 0.50-16
	51P1C	Maximum Phase Overcurrent 1 Curve. The curve options are same as given for 51AC.	U1, U2, U3, U4, U5 C1, C2, C3, C4, C5
	51P1TD	Maximum Phase Overcurrent 1 Time Dial. 0.50-15.00 for US curves. 0.05-1.00 for IEC curves.	0.50 - 15.00 0.05 - 1.00
	51P1RS	Maximum Phase Overcurrent 1 EM Reset Delay.	Y or N, Default N
	51P1CT	Maximum Phase Overcurrent 1 Constant Time Adder.	0.00-1.00
	51P1MR	Maximum Phase Overcurrent 1 Minimum Response Time.	0.00-1.00
	51P1TC	Maximum Phase Overcurrent 1 Torque Control. This bit can be assigned a SELogic expression. When this bit is true only then will 51P1P protection will work. If no external control is required then it should be set to 1.	Default value used, if no logical or external control is required, is 1
	51P2P	Maximum Phase Overcurrent 2 Trip Level. This should be set so that maximum current through a phase does not exceed 3.5A.	OFF, 0.50-16
	51P2C	Maximum Phase Overcurrent 2 Curve. The curve options are same as given for 51AC.	U1, U2, U3, U4, U5 C1, C2, C3, C4, C5
	51P2TD	Maximum Phase Overcurrent 2 Time Dial. 0.50-15.00 for US curves. 0.05-1.00 for IEC curves.	0.50 - 15.00 0.05 - 1.00
	51P2RS	Maximum Phase Overcurrent 2 EM Reset Delay.	Y or N (default N)
	51P2CT	Maximum Phase Overcurrent 2 Constant Time Adder.	0.00-1.00
	51P2MR	Maximum Phase Overcurrent 2 Minimum Response Time.	0.00-1.00
	51P2TC	Maximum Phase Overcurrent 2 Torque Control.	Default value used, if no logical or external control is required, is 1
	51QP	Negative Sequence Time Overcurrent Trip Level. This should be set so that maximum current through a phase does not exceed 3.5A.	OFF, 0.50-16

	51QC	Negative Sequence Time Overcurrent Curve. The curve options are same as given for 51AC.	U1, U2, U3, U4, U5 C1, C2, C3, C4, C5
	51QTD	Negative Sequence Time Overcurrent Time Dial. 0.50-15.00 for US curves. 0.05-1.00 for IEC curves.	0.50 - 15.00 0.05 - 1.00
	51QRS	Negative Sequence Time Overcurrent EM Reset Delay.	Y or N (default = N)
	51QCT	Negative Sequence Time Overcurrent Constant Time Adder	0.00-1.00
	51QMR	Negative Sequence Time Overcurrent Minimum Response Time.	0.00-1.00
	51QTC	Negative Sequence Time Overcurrent Torque Control.	Default value used, if no logical or external control is required, is 1
	51N1P	Neutral Time Overcurrent Trip Level 1. We are not using neutral through the relay. So, this can be set at OFF.	OFF, 0.50-16
	51N2P	Neutral Time Overcurrent Trip Level 2.	OFF, 0.50-16
	51G1P	Residual Time Overcurrent Trip Level 1. This should be set so that maximum current through a phase does not exceed 3.5A.	OFF, 0.50-16
	51G1C	Residual Time Overcurrent Curve 1. The curve options are same as given for 51AC.	U1, U2, U3, U4, U5 C1, C2, C3, C4, C5
	51G1TD	Residual Time Overcurrent Time Dial 1. 0.50-15.00 for US curves. 0.05-1.00 for IEC curves.	0.50 - 15.00 0.05 - 1.00
	51G1RS	Residual Time Overcurrent EM Reset Delay 1.	Y or N, Default N
	51G1CT	Residual Time Overcurrent Constant Time Adder 1.	0.00-1.00
	51G1MR	Residual Time Overcurrent Minimum Response Time 1.	0.00-1.00
	51G1TC	Residual Time Overcurrent Torque Control 1.	Default value used, if no logical or external control is required, is 1
	51G2P	Residual Time Overcurrent Trip Level 2. This should be set so that maximum current through a phase does not exceed 3.5A.	OFF, 0.50-16
	51G2C	Residual Time Overcurrent Curve 2. The curve options are same as given for 51AC.	U1, U2, U3, U4, U5 C1, C2, C3, C4, C5
	51G2TD	Residual Time Overcurrent Time Dial 2. 0.50-15.00 for US curves. 0.05-1.00 for IEC curves.	0.50 - 15.00 0.05 - 1.00
	51G2RS	Residual Time Overcurrent EM Reset Delay 2.	Y or N, Default N
	51G2CT	Residual Time Overcurrent Constant Time Adder 2.	0.00-1.00
	51G2MR	Residual Time Overcurrent Minimum Response Time 2.	0.00-1.00
	51G2TC	Residual Time Overcurrent Torque Control 2.	Default value used, if no logical or external control is required, is 1
Voltage Protection Settings	27P1P	Under Voltage Trip 1 Level. This should be set for wye connection.	OFF, (0.02–1.00) xVNOM for delta OFF, (0.02–1.00) xVNOM/1.732 for wye
	27P2P	Under Voltage Trip 2 Level. This should be set for wye connection.	OFF, (0.02–1.00) xVNOM for delta OFF, (0.02–1.00) xVNOM/1.732 for wye

	59P1P	Over Voltage Trip 1 Level. This should be set for wye connection.	OFF, (0.02–1.00) xVNOM for delta OFF, (0.02–1.00) xVNOM/1.732 for wye
	59P1D	Over Voltage Trip 1 Delay	0.0–120.0
	59P2P	Over Voltage Trip 2 Level. This should be set for wye connection.	OFF, (0.02–1.00) xVNOM for delta OFF, (0.02–1.00) xVNOM/1.732 for wye
Power Factor Protection Settings	55LGTP	Power Factor Lag Trip Level	OFF, 0.05–0.99
	55LDTP	Power Factor Lead Trip Level	OFF, 0.05–0.99
	55LGAP	Power Factor Lag Warning	OFF, 0.05–0.99
	55LDAP	Power Factor Lead Warning	OFF, 0.05–0.99
Frequency Protection Settings	81D1TP	Frequency 1 Trip Level	OFF, 20.00–70.00 Hz
	81D2TP	Frequency 2 Trip Level	OFF, 20.00–70.00 Hz
	81D3TP	Frequency 3 Trip Level	OFF, 20.00–70.00 Hz
	81D4TP	Frequency 4 Trip Level	OFF, 20.00–70.00 Hz
Trip/Close Logic Settings	TDURD	Minimum Trip Time for which TRIP is asserted (sec)	0.0–400.0
	CFD	Close Fail Delay (sec)	0.0–400.0
	TR	Trip Equation (SEL Trip equation). TR word bit is the output of the SEL equation that includes the protection	SEL logic equation Default value used =ORED50T OR ORED51T OR 81D1T OR 81D2T OR 81D3T OR 81D4T OR 59P1T OR 59P2T OR 55T OR REMTRIP OR SV01 OR OC OR SV04T
	REMTRIP	Remote Trip Equation	SEL logic equation Default value used = 0
	ULTRIP	Unlatch Trip	SEL logic equation Default value used= NOT (51P1P OR 51G1P OR 51N1P OR 52A)
	52A	Breaker Status. Contact from a breaker can be connected to an input contact of the relay. This input can be assigned to this bit to include the breaker status for example in Unlatch Trip (ULTRIP) logic.	SELogic equation Default value used = 0
	CL	Close Equation	SEL logic equation Default value used= SV03T AND LT02 OR CC
	ULCL	Unlatch Close	SEL logic equation Default value used = 0

SEL-751A Relay Logic Settings SHO L and SET L			
Logic Settings	ELAT	Enable Setting of SELogic Latches. In this setting the number of latch bits that have to be enabled are entered.	Default used = 4
	ESV	Enable Setting of SEL Variables (SV)/Timers	Default used = 4
	ESC	Enable Setting of SELogic Counters	Default set at= N
	EMV	Enable Setting of Math Variables	Default set at= N
	SET01	SET logic bit 1. This is related with latch bit LT01. SET01 can be assigned a SELogic expression. When the assigned logic becomes true, SET01 will become 1 and the corresponding latch bit LT01 will be set at 1.	Default set at= NA
	RST01	RESET logic bit 1. This is related with latch bit LT01. RST01 can be assigned a SELogic expression. When the assigned logic becomes true, RST01 will become 1 and the corresponding latch bit LT01 will reset (becomes 0).	Default set at= NA
	SET02	SET logic bit 2. Similar to SET01.	Default set at = R_TRIG SV02T AND NOT LT02
	RST02	RESET logic bit 2. Similar to RST01.	Default set at = R_TRIG SV02T AND LT02
	SET03	SET logic bit 3. Similar to SET01.	Default set at= PB03_PUL AND LT02 AND NOT 52A
	RST03	RESET logic bit 3. Similar to RST01.	Default set at= (PB03_PUL OR PB04_PUL OR SV03T) AND LT03
	SET04	SET logic bit 4. Similar to SET01.	Default set at= PB04_PUL AND 52A
	RST04	RESET logic bit 4. Similar to RST01.	Default set at= (PB03_PUL OR PB04_PUL OR SV04T) AND LT04
	SV01PU	SEL Logic Variable SV01 Timer Pickup	0.00–3000.00
	SV01DO	SEL Logic Variable SV01 Dropout	0.00–3000.00
	SV01	SEL Logic Variable SV01 Input	SEL logic equation Default value used= WDGTRIP OR BRGTRIP OR OTHTRIP OR AMBTRIP OR (27P1T OR 27P2T) AND NOT LOP)
	SV02PU	SEL Logic Variable SV02Timer Pickup	0.00–3000.00
	SV02DO	SEL Logic Variable SV02 Dropout	0.00–3000.00

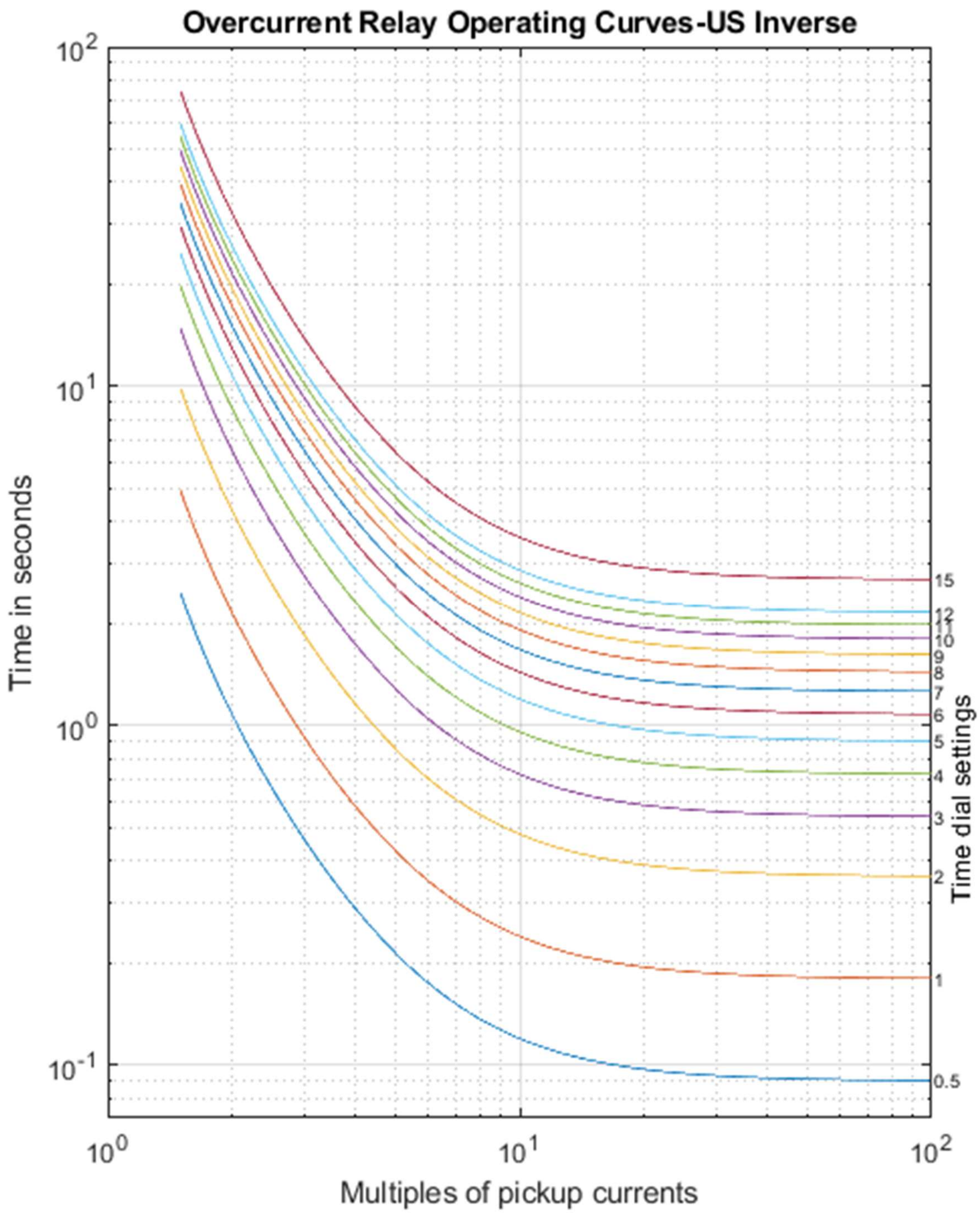
	SV02	SEL Logic Variable SV02 Input	SEL logic equation Default value used= PB02
	SV03PU	SEL Logic Variable SV03 Timer Pickup	0.00–3000.00
	SV03DO	SEL Logic Variable SV03 Dropout	0.00–3000.00
	SV03	SEL Logic Variable SV03 Input	SEL logic equation Default value used= LT03
	SV04PU	SEL Logic Variable SV04 Timer Pickup	0.00–3000.00
	SV04DO	SEL Logic Variable SV04 Dropout	0.00–3000.00
	SV04	SEL Logic Variable SV04 Input	SEL logic equation Default value used= LT04
	SV05PU	SEL Logic Variable SV05 Timer Pickup	0.00–3000.00
	SV05DO	SEL Logic Variable SV05 Dropout	0.00–3000.00
	SV05	SEL Logic Variable SV05 Input	SEL logic equation Default value used= (PB02 OR LT03 OR LT04) AND NOT SV05T
	OUT101FS	Output 101 Fail Safe. In the fail-safe mode the output relay remains energized under normal condition and it deenergizes when a trip occurs.	Y, N Default value used= N
	OUT101	Output 101. The default is set at HALARM (hardware self-test warning) or SALARM (software conditions such as access level changes, settings changes, password change etc.)	Default set at= HALARM OR SALARM
	OUT102FS	Output 102Fail Safe	Y, N Default set at= N
	OUT102	Output 102	Default set at= CLOSE
	OUT103FS	Output 103 Fail Safe	Y, N Default set at= N
	OUT103	Output 103	TRIP
	OUT301FS	Additional Output 1 fail-safe	Y, N Default set at= N
	OUT301	Additional Output 1 at Slot C.	Default set at= 0
	OUT302FS	Additional Output 2 fail-safe	Y, N Default set at= N
	OUT302	Additional Output 2 at Slot C.	Default set at= 0
	OUT303FS	Additional Output 3fail-safe	Y, N Default set at= N
	OUT303	Additional Output 3 at Slot C.	Default set at= 0
	OUT304FS	Additional Output 4 fail-safe	Y, N Default set at= N
	OUT304	Additional Output 4 at Slot C.	Default set at= 0

SEL-751A Relay Global Settings SHO G and SET G			
General Settings	PHROT	Phase Rotation. ABC or ACB can be selected.	Default value set at= ABC
	FNOM	Nominal (rated) frequency of the system in Hz. 50 or 60Hz can be selected.	Default value set at= 60 Hz
	DATE_F	Date format.	MDY or YMD Default at= MDY
	FAULT	A SELogic equation can be assigned. This can temporarily block energy and demand metering.	Default set at= 50G1P OR 50N1P OR 51P1P OR 51QP OR 50Q1P OR TRIP
	EMP	Enable event messenger points.	N, 1-32. Default set at= N
Group Selection	TGR	Group change delay. Time is in seconds.	0-400 Default set at= 3
	SS1	Select Group 1. Group settings include all the protection settings of the relay. This bit can be assigned a SELogic equation. When the equation becomes true then Group 1 settings will be used. If no logic is assigned then it is given a value of 1 to enable the settings under Group1.	Default set at= 1
	SS2	Select Group 2. Same as SS1. By default settings under Group 1 are used. So, this bit is assigned a 0 value to disable this group.	Default set at= 0
	SS3	Select Group 3. Same as SS1. By default settings under Group 1 are used. So, this bit is assigned a 0 value to disable this group.	Default set at= 0
Breaker Failure Settings	52ABF	52A Interlock. This enables to detect a breaker failure.	Y, N Default set at= N
	BFD	Breaker failure delay. This will set a delay in operation of breaker failure trip. Time in seconds.	0.00-2.00
	BFI	Breaker failure initiate. This word bit can be assigned a SELogic equation to initiate the breaker failure.	Default set at= R_TRIG TRIP
Base Input Debounce Settings	IN101D	Input 1 debounce settings. Input is asserted when the input signal remains at a state for at least the time specified in this setting. Times in milliseconds.	0-65000 Default at= 10
	IN102D	Input 2 debounce settings. Input is asserted when the input signal remains at a state for at least the time specified in this setting. Times in milliseconds.	0-65000 Default at= 10
Slot C Input Debounce Settings	IN301D	Same as IN101D and IN102D.	0-65000 Default at= 10
	IN302D	Same as IN101D and IN102D.	0-65000 Default at= 10
	IN303D	Same as IN101D and IN102D.	0-65000 Default at= 10
	IN304D	Same as IN101D and IN102D.	0-65000 Default at= 10
Data Reset	RSTTRGT	Reset Targets. This word bit can be assigned a SELogic equation. This will reset trip output and the front Trip LED however, for that to happen there should be trip condition present.	Default set at= 0
	RSTENRGY	Reset energy metering values. This can be assigned a SELogic expression.	Default set at= 0

	RSTMXMN	Reset Min/Max metering values. This can be assigned a SELogic expression.	Default set at= 0
Access Control	DSABLSET	Disable setting changes from the front panel of relay. This can be assigned a SELogic equation. For example, DSABLSET=IN302 will not allow setting changes from the front panel when IN302= 1.	Default set at= 0

C- US Inverse Time Relays Operating Time vs. Multiples of Pick-up Current

The curves are based on $Operating\ Time = Time\ Dial \times \left(\frac{5.95}{(Multiples\ of\ Pickup\ Current)^2 - 1} + 0.180 \right)$, provided in SEL [2].



D- List of Passwords

Lab PC	
User Name	aperc
Password	aperc

SEL-3351 Computing Platform	
User Name	Admin
Password	Passwordaperc1

AcSELerator QuickSet Database Logging Details	
Connection Name	Default AcSELerator Database Connection
Server	localhost
Port	5434
Database	SEL Master Database
User Name	admin
Password	aperc

SEL-751A	
Level 1	OTTER
Level 2	TAIL

E- Parts List

Sr#	Device Details	Qty
1	GE Industrial Circuit Breaker, Cat. No. TED134010, 10 Amp. 480 VAC, 50/60Hz. 250 VDC. Wire Range: #14--#8 CU #12--#8 AL Torque: #14-#8 35 lb.-in Interrupting Rating RMS Sym. Amps, Volts kA 240 5 480 5 250DC 5 Shunt Trip Device Rating: 125VDC, 1.0 Amps	1
2	General Radio Company Type W10H VARIAC®	1
3	Westinghouse Type CO-8 Overcurrent Relay, 60 Hz, Overcurrent Unit: 0.5-2.5 Amps, Indicator: 0.2-2 Amps DC, Catalogue: CO-8L1101N, STYLE: 264C900A01, Instruction Leaflet: 41-100, Schematic: 57D4523.	6
4	General Electric 6476K51052, 0-300 AC Volts Voltmeter.	1
5	General Electric 6657K10001, 0-5 AC Amperes Ammeter.	1
6	SEL-751A Feeder Protection Relay, P/N: 751A51A1A0X71850210.	2
7	SEL-3351 System Computing Platform, P/N: 33513574XH0004EGA00.	1

8	Omron G3NA-420B Solid State Relay, Input: 5-24 VDC, Load 200-480VAC, 20A.	3
9	CS21029-G32-L22LBAB61 - BTO Changeover, Switch with Off Position, Maintained 60 Degree, 5 Poles, 32A, IP20 Terminals, 22.5mm Installation, 48mm x 48mm Front Plate, Lever Knob Black/Aluminum, 1-0-2 (60). Manufacturer: C3 Controls.	2
10	Omron LY2F-DC12 General-Purpose Relay, Standard Type, Plug-In/Solder Terminal, Upper Mounting Bracket, Single Contact Double Pole Double Throw Contacts, 75 mA Rated Load Current, 12 VDC Rated Load Voltage.	1
11	(Pack of 2 Pieces) Chanzon KBPC5010 Bridge Rectifier Diode 50A 1000V KBPC Single Phase, Full Wave 50 Amp 1000 Volt Electronic Silicon Diodes.	1 Diode Used
12	100uF 400V 18X30 +/-20% +105℃ 6 PCS Aluminum Electrolytic Capacitors.	1
13	2 of PVC (Polyvinyl Chloride) Sheet, Opaque White, Standard Tolerance, UL 94/ASTM D1784, 1/4" Thickness, 12" Width, 12" Length.	2 Sheets
14	2 of PVC (Polyvinyl Chloride) Sheet, Opaque White, Standard Tolerance, UL 94, 1/8" Thickness, 12" Width, 12" Length.	2 Sheets
15	Pinfox 2 Pack Black Waterproof Plastic Project Box ABS IP65 Electronic Junction box Enclosure 3.94 x 2.68 x 1.97 inch (100 x 68 x 50 mm).	1 Box Used

16	Yootop Wirewound Resistor 100W 50 Ohm 5% Tolerance Chassis Mounted Aluminum Housed 2Pcs.	1 Resistor Used
17	Momentary Contact Switch	1
18	Single Pole Double Throw Toggle Switch	1
19	Westinghouse EHB3010 Circuit Breaker. 480 VAC, 3 Pole, 40°C.	1
20	Cerrowire Vinylon-1, 12 AWG Wire. 600 V.	1 Roll

References

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[3] Schweitzer Engineering Laboratories, Inc., "AcSELerator QuickSet SEL-5030 Software Instruction Manual," 06 March 2019. [Online]. Available: https://selinc.com/products/5030/#tab-literature. [Accessed 10 June 2019].

[4] Schweitzer Engineering Laboratories, Inc., "SEL-387A Relay Current Differntial Instruction Manual," 01 June 2017. [Online]. Available: https://selinc.com/products/387A/. [Accessed - November 2018].

[5] SUBNET Solutions Inc., "SubstationSERVER.NET Getting Started Guide," SUBNET Solutions Inc., 2007.

[6] ABB, "Type CO Overcurrent Relay Class-1E Application Instruction Leaflet 41-100.1C," - May 2009. [Online]. Available: https://library.e.abb.com/public/e2127de14e1f16c8852575bd0056fa5e/41-100-1C.pdf. [Accessed 27 June 2019].